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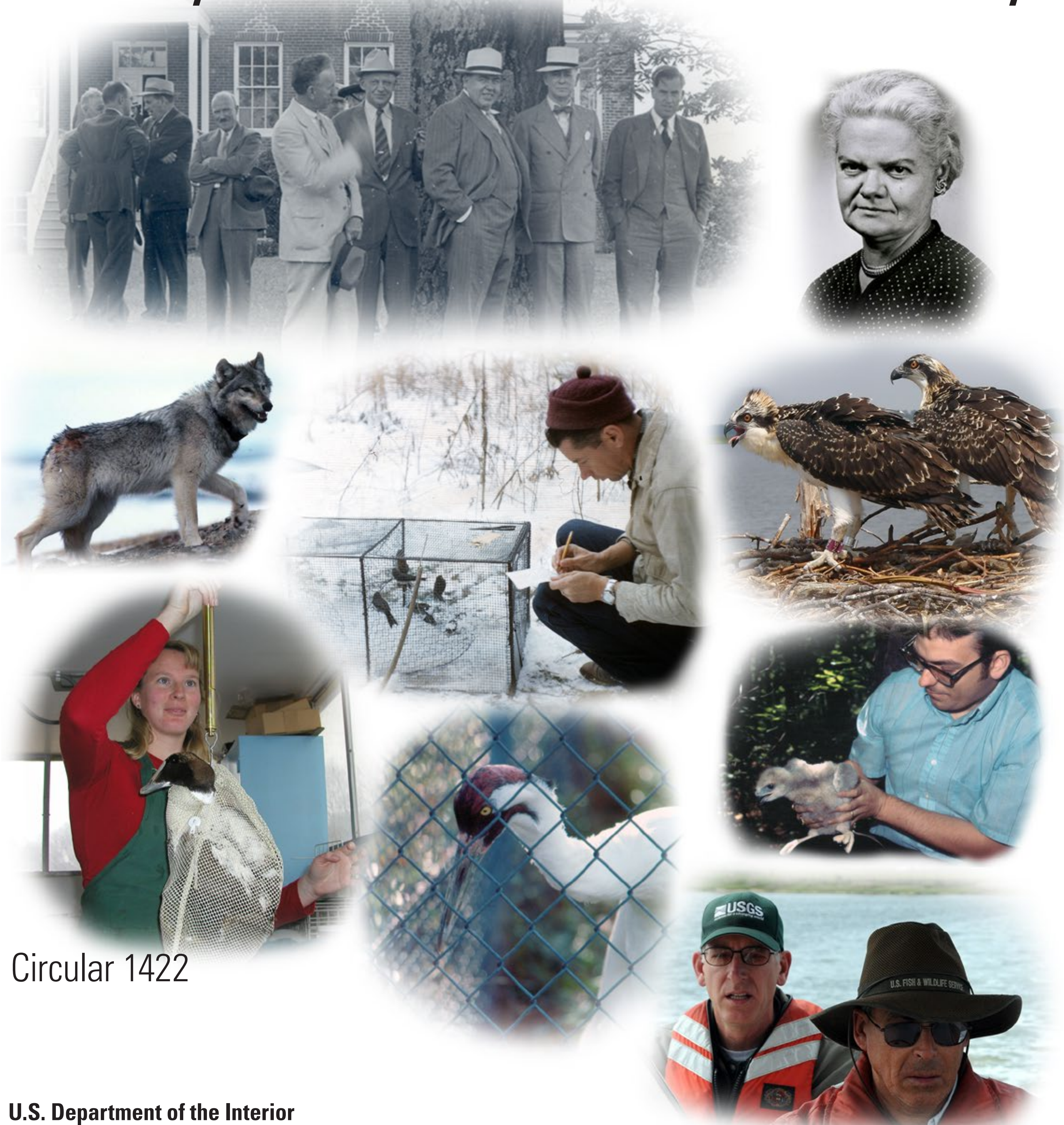
The History of Patuxent: America's Wildlife Research Story



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Cover. Clockwise from top, left: Dedication of Patuxent Research Refuge at Snowden Hall, Laurel, MD, June 1939 (Photo by Bureau of Biological Survey); Dr. Lucille Stickel, U.S. Fish and Wildlife Service, an important research scientist in 1940s to 1960s and Director of Patuxent Wildlife Research Center in 1970s to 1980s (Photo by U.S. Fish and Wildlife Service); banded young ospreys on nest in Chesapeake Bay, 2012 (Photo by Rebecca S. Lazarus, U.S. Geological Survey); Chuck Henny, U.S. Fish and Wildlife Service, holding a red-tailed hawk prior to banding, Patuxent Research Refuge, spring 1972 (Photo by Matthew C. Perry, U.S. Fish and Wildlife Service); Barnett Rattner, U.S. Geological Survey (left), and Pete McGowan, U.S. Fish and Wildlife Service, Chesapeake Bay, 2013 (Photo by Reese F. Lukei, Jr., Center for Conservation Biology, College of William and Mary, Williamsburg, VA); whooping crane named Canus at Patuxent Wildlife Research Center, 1991 (Photo by Matthew C. Perry, U.S. Fish and Wildlife Service); Alicia Berlin, U.S. Geological Survey, weighing common eider in seaduck colony for selenium study at Patuxent Wildlife Research Center, 2004 (Photo by Matthew C. Perry, U.S. Geological Survey); wolf with collar-mounted transmitter being tracked by David Mech, U.S. Fish and Wildlife Service, in Minnesota (Photo by U.S. Fish and Wildlife Service). Center: Chan Robbins, U.S. Fish and Wildlife Service, recording data on birds in trap at Patuxent Research Refuge, late 1940s (Photo by U.S. Fish and Wildlife Service).

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Edited by Matthew C. Perry

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U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

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Foreword

The facility known as Patuxent has evolved from the original Patuxent Research Refuge to the Patuxent Wildlife Research Center, and eventually to a two-agency facility with two clear, though distinct, missions. President Franklin D. Roosevelt established Patuxent as the Nation's first wildlife research station through an Executive Order in 1936. Originally, the research and wildlife conservation missions were conjoined; these missions continue today, but under two different agencies in a collaborative partnership. The U.S. Geological Survey (USGS) administers Patuxent Wildlife Research Center and the U.S. Fish and Wildlife Service (USFWS) administers Patuxent Research Refuge. Together, they are "Patuxent."

Great conservation icons such as Mr. J.N. "Ding" Darling and Dr. Ira N. Gabrielson were instrumental in establishing Patuxent and investing in America's great conservation future, even as the country was in the midst of the Great Depression. Through the years, the staff of Patuxent has been at the forefront of scientific achievement in the study of migratory birds, environmental contaminants, and endangered species. Innovations of Patuxent scientists have pushed the limits of techniques for field investigations, including the use of satellite telemetry, that have facilitated successful biological investigations throughout the world. Changes in research methods through the years have been prodigious, inasmuch as some naturalists early in Patuxent's history believed that banding and color-marking of birds were too invasive. Since then, USGS and USFWS staff at Patuxent have spearheaded the development and successful application of adaptive strategies and structured decision-making tools to real-world conservation and management issues. Patuxent's vision and mission define its purpose and direction. Working with a wide variety of partners is Patuxent's approach to ensuring that relevant, high-quality, objective science continues to support society's needs while maintaining its role as an active and productive Federal research institution.

Patuxent evolved from its origin in the U.S. Biological Survey to become the only research refuge of the USFWS, and then to assume its current position as one of 17 Biological Research Centers of the USGS, which is the natural resources research arm of the Department of the Interior. The USFWS, through the National Wildlife Refuge System, administers the Patuxent Research Refuge, and the two agencies remain focused on their primary mission of research and wildlife conservation. We invite you to explore Patuxent's history and the information presented in the pages that follow.

John B. French
Director, Patuxent Wildlife Research Center

Bradley A. Knudsen
Manager, Patuxent Research Refuge

Preface

Photo by Kinard Boone, U.S. Geological Survey.

This report, based on a symposium held on October 13, 2011, at the National Wildlife Visitor Center at the Patuxent Research Refuge in Laurel, MD, documents the history of the Patuxent Research Refuge and the Patuxent Wildlife Research Center, collectively known as Patuxent. The symposium was one of the many activities occurring at that time to celebrate the 75th anniversary of the creation of the Patuxent Research Refuge in 1936. The Patuxent Wildlife Research Center is located at the refuge, and the research center director, Dr. Gregory J. Smith, with great enthusiasm, personally supervised all aspects of the celebration. The symposium was coordinated by Dr. Matthew C. Perry, the editor of this report, with Dr. Smith's strong support. The refuge and the research center have been essentially synonymous for the almost 80 years of their history.

Dr. Smith's strong interest in Patuxent history and the symposium were major factors in the overwhelming success of the 75th anniversary celebration, in which he played a major role. Symposium attendees included a large number of dignitaries as well as virtually the entire staffs of the Patuxent Wildlife Research Center and the Patuxent Research Refuge.

Unfortunately, Dr. Gregory James Smith passed away at the age of 58 on April 11, 2014, while on official business in Beijing, China, where he was contributing to ongoing discussions on avian influenza and global climate change. Because of the importance of his contributions to wildlife science in general and Patuxent in particular, and because of his dedication to the publication of this report, a brief description of his life and career is included below.

Greg enrolled in Northern Michigan University and received his bachelor's degree in biology in 1978. He went on to earn a master's degree in wildlife ecology and a Ph.D. in wildlife ecology and veterinary science from the University of Wisconsin—Madison in 1984. Greg's passion for the environment directed his entire career path.

Having more than 35 years of ecological research and management experience, Greg spearheaded many environmental initiatives. His career began with post-doctoral studies at the Patuxent Wildlife Research Center and came full circle when he became the director of the research center in 2009. During his career, he also was appointed director of the National Wetlands Research Center in Lafayette, LA, in 2004, and the Great Lakes Science Center in Ann Arbor, MI, in 1996, making him the first and only person to direct three different U.S. Geological Survey wildlife research centers.

Greg felt privileged to work in partnership with scientists and friends in Russia and Southeast Asia. He was particularly proud of projects on the Mekong River and his relationships with the many partners who live and work there. He was honored to serve on the board of the National Wildlife Federation and devoted time and energy to the mission of that organization.

In his first year as director of the National Wetlands Research Center, the Gulf Coast and particularly New Orleans were ravaged by two hurricanes, Katrina and Rita. Greg rushed into action, using the Center's boats as life-saving vessels for New Orleans victims, and personally rescuing families in dire trouble during the aftermath. For these efforts, his team was awarded the Service to America Medal by the nonpartisan Partnership for Public Service, to honor excellence in Federal civil service.

Greg had not only a passion for his work, but also a passion for life. He loved the sea and was an avid sailor, building boats and chartering trips around the Caribbean during his college days. Greg continued to pursue this interest throughout his life, racing sailboats in Chesapeake Bay and around the world. He shared his love of the sea with his family, marrying Kathy, his wife, on their boat and spending weekends with their two children on the water.

He traveled to more than 65 countries, making friends and finding adventure with every step—from hiking through the Tibetan Himalayas, to diving the oceans, to trekking through jungles and savannahs. The lives he touched span the world.

Greg loved Patuxent and took pride in its long and distinguished history. He was director during the 75th anniversary and supported all of the celebratory activities with great excitement. He was especially supportive of this project—to publish a report based on the proceedings of the symposium held at Patuxent during the anniversary celebration. The Patuxent community misses him greatly; we acknowledge his contributions to wildlife science and honor his memory by fulfilling his wish to publish this report about the history of Patuxent.

Acknowledgments

The authors gratefully acknowledge Shannon Beliew of the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center (Patuxent) for logistical assistance; Lynda J. Garrett, USGS Patuxent librarian (retired), for invaluable assistance with literature searches and editing; and Dale L. Simmons, USGS, for outstanding editing.

Contents

Conversion Factors

[Inch/Pound to International System of Units]

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Application rate	
pounds per acre per year [(lb/acre)/yr]	1.121	kilograms per hectare per year [(kg/ha)/yr]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as:

$$°C = (°F - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

<	less than
>	greater than
AHM	Adaptive Harvest Management
ALAD	aminolevulinic acid dehydratase
AOU	American Ornithologists' Union
ARM	Adaptive Resource Management
ARMI	USGS Amphibian Research and Monitoring Initiative
ARP	Accelerated Research Program
BARC	Beltsville Agricultural Research Center
BBL	Bird Banding Laboratory
BBS	Breeding Bird Survey
BDJV	Black Duck Joint Venture
BHC	benzene hexachloride
BLM	Bureau of Land Management
BRD	Biological Resources Discipline
BSFW	Bureau of Sport Fisheries and Wildlife
CBC	Christmas Bird Count
CCC	Civilian Conservation Corps
CCS	Call-Count Survey
ChE	cholinesterase
CPV	canine parvovirus
CSA	Cambridge Scientific Abstracts
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DEW	Distant Early Warning
DLNR	Department of Land and Natural Resources
DMBM	Division of Migratory Bird Management
DNA	deoxyribonucleic acid
DNR	Department of Natural Resources
DOI	Department of the Interior
EDTA	ethylenediaminetetraacetic acid
FEPCA	Federal Environmental Pesticides Control Act

FY	fiscal year
GAP	Gap Analysis Program
GPS	global positioning system
GS	General Schedule
HAB	harmful algal bloom
HCP	habitat conservation plan
HDFW	Hawaii Department of Forestry and Wildlife
HFBS	Hawaiian Forest Bird Survey
HIP	Harvest Information Program
IAFWA	International Association of Fish and Wildlife Agencies
IBCC	International Bird Census Committee
IBWO	ivory-billed woodpecker
IIT-RI	Illinois Institute of Technology-Research Institute
IITF	International Institute of Tropical Forestry
ILL	interlibrary loan
IPDS	Information Product Data System
IRM	Information Resources Management
IWBO	ivory-billed woodpecker
LSU	Louisiana State University
MBHRL	Migratory Bird and Habitat Research Laboratory
MBMO	Office of Migratory Bird Management (now, DMBM)
MBPS	Migratory Bird Population Station
MCP	minimum convex polygon
min	minute
MN	Minnesota
MOA	memorandum of agreement
MOS	Maryland Ornithological Society
MWI	Mid-winter inventory
NAAMP	Patuxent North American Amphibian Monitoring Program
NABCI	North American Bird Conservation Initiative
NAWMP	North American Waterfowl Management Plan
NBS	National Biological Survey
NGO	nongovernmental agency
NLCD	National Land Cover Data
NPS	National Park Service

NRDA	Natural Resource Damage Assessment
NWR	National Wildlife Refuge
OC	organochlorine
OCLC	Online Computer Library Center, Inc.
OP	organophosphate
PAH	polynuclear aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PC	personal computer
PCB	polychlorinated biphenyl
ppm	parts per million
PRDNR	Puerto Rico Department of Natural Resources
PRR	Patuxent Research Refuge
PWRC	Patuxent Wildlife Research Center
SAAMI	Sporting Arms and Ammunition Manufacturers' Institute
SDM	Structured Decision-Making
SE	standard error
SGS	Singing-Ground Survey
SNF	Superior National Forest
SOS	Save Our Shearwaters
TQM	total quality management
URL	Universal Resource Locator
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WBS	Winter Bird Survey
WMA	wildlife management area
ww	wet weight

Patuxent's Development: The People and the Projects

By Matthew C. Perry

Dedication of Patuxent Research Refuge at Snowden Hall, Laurel, MD, June 1939. Photo by Bureau of Biological Survey.

Early Wildlife Conservation Research

Although several conservation activities took place in the United States in the early 1900s, it was not until the 1930s that scientific wildlife management and the research to support it were initiated. The formation of Patuxent Research Refuge (Patuxent) was one of many wildlife conservation activities that occurred in the mid-1930s. On December 16, 1936, President Franklin D. Roosevelt signed Executive Order 7514, which transferred 2,670 acres of land that had been acquired (or would be acquired) by the United States to the Department of Agriculture (USDA) as a wildlife experiment and research refuge. The area delineated in the order was located in Anne Arundel and Prince George's Counties, MD, and was created "to effectuate further the purposes of the Migratory Bird Conservation Act." By order of the President, the area was to be known as "the Patuxent Research Refuge."

The refuge was dedicated on June 3, 1939, at Snowden Hall by Secretary of Agriculture Henry A. Wallace, who stated that "the chief purpose of this refuge is to assist in the restoration of wildlife—one of our greatest natural resources." Secretary Wallace recognized "the vision and foresight of Dr. Ira N. Gabrielson, Chief of the Biological Survey," and "the leadership of Dr. Leland C. Morley, superintendent of the refuge." He further stated that the Nation's first wildlife research station was "the manifestation of a national determination and a national ability to conserve and administer wisely the organic resources and products of the soil—a priceless heritage to the generations of Americans yet to come." Although Mr. Jay N. "Ding" Darling, former Chief of the Bureau of Biological Survey, was not present or mentioned in Secretary Wallace's address, many people also credit the formation of the Patuxent Research Refuge to his interest and support.

Superintendent Dr. Leland C. Morley in front of Log Cabin—Patuxent Research Refuge's first office building. Photo by Bureau of Biological Survey.

Snowden Hall at the Patuxent Research Refuge, Laurel, MD, about 1936. Photo by Bureau of Biological Survey.

Patuxent's location adjacent to the Beltsville Agricultural Research Center at Beltsville, MD, made it an appropriate area, according to Wallace, upon which to conduct "long-time studies on the interrelationships of wildlife with agriculture and forestry." Secretary Wallace and Dr. Gabrielson envisioned an area where wildlife could be studied in relation to the production of agricultural crops, and where lands poorly suited for agriculture could be turned back into forests, fields, and meadows, thus again becoming productive for wildlife.

An interesting change in the relation between humans and wildlife, however, had taken place during the 1930s. Previously, wildlife investigations in the USDA had focused on the impact of wildlife on activities of humans; however, the long drought of the 1930s coupled with decades of wetland drainage by humans devastated North America's waterfowl populations. Consequently, Americans were becoming more aware of the negative effects of their activities on wildlife. It was appropriate, therefore, that in 1939 the Bureau of Biological Survey was transferred from the USDA to the Department of the Interior (DOI). By 1940, the Bureau of Biological Survey was replaced by the Fish and Wildlife Service. It was not until 1956 that Congress renamed this agency the U.S. Fish and Wildlife Service (USFWS).

Dr. Leland C. Morley was superintendent of the refuge during the embryonic years from 1938 to 1948. He was responsible for the construction and development of the facilities to be used for wildlife research (Morley, 1948). Under his administration, three major buildings (Merriam, Henshaw, and Nelson Laboratories), named for the first three chiefs of the Bureau of Biological Survey, were constructed in 1939-41 through the efforts of the Works Progress Administration and the Public Works Administration headquartered in Washington, D.C. Some of the early Patuxent biologists traveled between Patuxent and their homes in Washington in trucks used to transport construction workers. On-site quarters were constructed for some biologists in the early 1940s to allow researchers to remain near their work. The first wetland area, Cash Lake, was built by the Civilian Conservation Corps (CCC) and was flooded in 1939 as a recreational area for fishing. The CCC was also responsible for transplanting many trees from the woods to landscape the new buildings.

With the outbreak of World War II, many of the Patuxent men were called for military service. Older male staff members and some women continued the wildlife conservation work and, beginning in 1943, were assisted by the Civilian Public Service Program, which established at Patuxent a group of conscientious objectors to the war. These men were credited with constructing Snowden Pond and several roads, and conducting surveys of wildlife and plants.

Dr. Morley supervised construction at Patuxent during the late 1930s and early 1940s. Research, however, was directed by administrators in Washington through their assistants, who were working at Patuxent. Dr. Alexander C. Martin was in charge of food habits research, which was located in Merriam Laboratory. Wildlife disease research, headed initially by Dr. J.E. Shillinger and later by Dr. Donald Coburn, was located in

Works Progress Administration workers at Patuxent Research Refuge, Laurel, MD. Photo by Bureau of Biological Survey.

Civilian Public Service Program members at Snowden Hall, Patuxent Research Refuge, Laurel, MD. Photo by Bureau of Biological Survey.

Henshaw Laboratory. All bird banding studies were administered in Nelson Laboratory and conducted at field locations throughout the country.

From 1942 to 1948, Mr. Arnold L. Nelson supervised all research at Patuxent from the Washington headquarters. In 1948, his office was moved to Patuxent, and he served as Patuxent's first official director until his retirement in 1959. Dr. Gustav Swanson became Chief of Research at headquarters. Mr. Nelson's responsibilities included both land management and research. The farm game research, which compared the diversity and numbers of wildlife under various farming practices, began under Mr. Nelson. Dr. Durward Allen headed this program, which compared two major farm practices, one that provided good wildlife habitat and one that did not (Warbach, 1958). The program was terminated before it reached its full potential for production of data, but many findings were published in popular outlets and used by farmers and refuges throughout the country. Dr. Allen authored "The Farmer and Wildlife," which was published by the Wildlife Management Institute and had seven printings (Allen, 1949). Dr. Allen also published "Our Wildlife Legacy," which includes much of the findings about optimum wildlife management techniques that were developed at Patuxent (Allen, 1954).

Long-term studies of certain single species forest wildlife, including box turtles (*Terrapene carolina*), black rat snakes (*Elaphe obsoleta*), and red-shouldered hawks (*Buteo lineatus*), also were initiated in the 1940s to 1950s. These species were optimum for long-term studies as they are common at Patuxent and can be captured and marked relatively easily. The box turtle studies initially were overseen by Dr. Lucille Stickel, but were later led by Dr. Russell Hall and then Dr. Paula Henry. Mr. William Stickel headed the black snake studies, which sometimes sent most of the staff searching for snakes. Mr. Elwood Martin and Dr. Charles Henny continued the red-shouldered hawk studies begun by Mr. Frederick Schmid. These programs represent some of the longest studies conducted on single species of wildlife. Extensive surveys were also conducted on all bird species at Patuxent during different seasons (Stewart and others, 1952).

Mr. Nelson was instrumental in continuing the development of the refuge for wildlife, while promoting research that would document habitat management techniques most beneficial for wildlife. Patuxent's first field station was established in Alabama to evaluate the interrelations between quail populations and habitat manipulations. Most of the waterfowl impoundments that exist today at Patuxent were developed during Mr. Nelson's tenure, and studies were begun to determine how best to manage those areas for wildlife. Techniques developed at Patuxent to help farm game and wetland species were widely adopted throughout the country.

In 1956, the Patuxent Research Refuge was renamed the Patuxent Wildlife Research Center to standardize the name with the adjacent Agricultural Research Center and with another USFWS facility in Denver, CO. The name change was done by administrative memorandum and did not supersede the original Executive Order designation as a Research Refuge.

Dr. Gustav Swanson (left), Research Chief, U.S. Fish and Wildlife Service, and Mr. Arnold Nelson, Director of Patuxent Research Refuge (PRR), at Cash Lake, PRR, Laurel, MD, on January 8, 1954. Photo by Francis M. Uhler, Patuxent Research Refuge.

The Environmental Movement and New Research

Dr. John L. Buckley became the director of Patuxent in 1959 and served until 1963. Under his leadership the pesticide research program, begun in the 1940s, was broadened to include other chemicals and became known as the Environmental Contaminants Research Program. An increased emphasis on experimental design and statistically controlled studies developed during this period. There was an increasing belief at Patuxent that field studies should receive less emphasis because of the difficulties inherent in controlling environmental and habitat variables that are not encountered in standardized pen studies. Observations in the field could now be tested under "laboratory" conditions.

Secretary of the Interior Stewart Udall dedicated a new building for the Environmental Contaminants Research Program in 1963. The building was originally named the Biochemistry and Wildlife Pathology Laboratory. Throughout his dedication speech, Secretary Udall referred to the work of Rachel Carson and her famous book, "Silent Spring," published in 1962. Ms. Carson never worked at Patuxent, but based some of her book on research done there. Interestingly, Ms. Carson never mentions Patuxent by name in her book, but refers to it as a laboratory near Laurel, MD. In 1989, the building was renamed Stickel Laboratory for Dr. Lucille and Mr. William Stickel, who had devoted a combined total of 78 years to research at Patuxent.

The bird control research program, which had been initiated by Mr. Nelson, was expanded during Dr. Buckley's tenure to become the Section of Animal Control Studies. The Wetland Ecology Section of Patuxent conducted waterfowl habitat management research, with major activities addressing water-level manipulation and artificial nesting structures taking place on the Patuxent grounds. Extensive studies of lead poisoning in waterfowl caused by the ingestion of spent lead-shot pellets began at this time and continued through the 1960s. In 1961, other migratory bird research and management programs, including the Bird Banding Laboratory, were consolidated in a newly established Migratory Bird Populations Station at Patuxent, headed by Mr. Walter F. Crissey (Crissey, 2006).

Dr. Eugene H. Dustman served as Patuxent's director from 1963 to 1972. During his tenure, Coburn Laboratory, the Service Building, and Gabrielson Laboratory were constructed. Gabrielson Laboratory was dedicated in 1969 in a well-attended celebration, and Dr. Gabrielson gave a speech. In 1969, Prince Charles of Great Britain and Mr. David Eisenhower, grandson of President Eisenhower, visited Patuxent and were given a tour led by Dr. Dustman and Dr. Stickel.

Prince Charles and David Eisenhower visit Patuxent Wildlife Research Center, Laurel, MD, 1969. Photo by U.S. Fish and Wildlife Service.

Dedication of Gabrielson Laboratory, Patuxent Wildlife Research Center, Laurel, MD, 1969. Photo by U.S. Fish and Wildlife Service.

Endangered Species Research

The Endangered Species Research Program began in 1965, headed by Dr. Ray C. Erickson, who also served as the first associate director of Patuxent. Although the first bald eagle arrived at Patuxent in 1961 as part of the contaminant program studies, the first bald eagle and whooping crane used in the endangered species program arrived at Patuxent in 1965 and 1966, respectively. This was the genesis of the captive propagation program that attained international prominence. The whooping crane was named Canus for Canada and United States, and reflected the close and long-lasting cooperation between the two countries with this species, which has continued since throughout the propagation program.

An additional 750 acres of land were purchased from the Shaefer family in 1970 as a buffer for the endangered species area, and several small support buildings, including a veterinary hospital, were constructed. A major endangered species laboratory was planned, but was never funded.

Innovative wetland management research was conducted during Dr. Dustman's era on approximately 300 acres of water impoundments that had been created at Patuxent. Improved nest boxes were designed for wood ducks, mallards, and black ducks, which greatly aided the nesting success of these species. Drawdown techniques for impoundments were perfected to optimize moist-soil management for waterfowl (Perry and others, 2000). A manual on wood duck habitat needs was disseminated and used extensively by managers across the country. These techniques were then employed in many states throughout the United States and in other countries. Mr. Frank McGilvrey published an article on starling deterrent nest boxes that could be used by wood ducks, but deterred nesting by the problematic starlings (McGilvrey and Uhler, 1971). Unfortunately, this optimum design was not widely accepted as a result of the ease of making wooden wood duck nest boxes originally designed by Mr. Frank Bellrose.

Patuxent's Wetland Ecology Section and part of the Migratory Bird Populations Station were combined in 1972 into a new group called the Migratory Bird and Habitat Research Laboratory (MBHRL) under the direction of Dr. Robert I. Smith and, later, Dr. Fant Martin. MBHRL personnel conducted extensive research on species of concern in specific geographic areas, including woodcock and black ducks in Maine, canvasbacks in Chesapeake Bay, and mourning doves in South Carolina.

Dr. Lucille F. Stickel became the director of Patuxent in 1973 and served in that capacity until her retirement in 1981. Under her leadership, environmental contaminants research expanded and attained national prominence. The expansion of this program is demonstrated by the average number of publications on contaminants produced per year, which increased from 4 in the 1950s to 7 in the 1960s, and then to 30 in the 1970s.

During the 1970s, all research and management activities related to the wetlands at Patuxent were curtailed because of new national priorities. This was a major turning point in the research on and management of the lands at Patuxent. Although biologists continued some activities with nest boxes and control of impoundment water levels on their own time, in general little on-site habitat research or management was conducted there during the 1970s.

Great egrets respond to moist-soil management, Patuxent Wildlife Research Center, Laurel, MD, 1987. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Frank McGilvrey and wood duck box, Patuxent Wildlife Research Center, Laurel, MD, 1972. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

In 1975, 1,250 acres of surplus land were transferred from the USDA to Patuxent, increasing the protection of Patuxent's wetlands by ensuring control of more of the watershed. The MBHRL was disbanded in 1981, and migratory bird research staff and projects were returned to Patuxent Wildlife Research Center under the leadership of Dr. Stickel. Patuxent lands were used to study forest fragmentation and population modeling, which, along with statistical methodology development, were major migratory birds research thrusts in the 1980s.

Much of the other migratory bird research continued to be species-oriented (especially ducks), and little wetland habitat research was conducted on Patuxent lands during the 1980s, although research was conducted in other areas, such as the work on waterfowl in the Chesapeake Bay ecosystem.

Patuxent's first master plan was prepared in 1980. The research mission statement was "The professional staff is engaged in research and management activities that are directed at accomplishing the principal missions of the Center: evaluation of the effects of environmental contaminants on wildlife and the environment; endangered species research and propagation; and migratory bird research (including urban wildlife) and management." A private consulting firm (Sasaki Associates, Inc.. Watertown, MA) wrote the master plan.

From 1982 to 1983, two acting directors, Drs. Russell J. Hall and John G. Rogers, Jr., who had been serving as assistant directors at the time of Dr. Stickel's retirement, managed Patuxent. During this period, the Reagan administration was searching for Federal land that could be sold as surplus to meet government needs. Agencies were asked to identify land that could be considered surplus, and Patuxent complied by offering about 50 acres. Because Patuxent was officially part of the National Wildlife Refuge System, however, Congress controlled any land negotiations. With help from the Honorable Steny Hoyer, U.S. Representative from Maryland, loss of Patuxent land was forestalled. This threat to the land and pressures from the increasing human population around it (including housing development, road construction, and siting of a landfill) led administrators to reassess how the lands at Patuxent were being used.

Transition to Public Outreach

Dr. David L. Trauger was appointed Patuxent director in 1983, following a 4-year stint as Chief, Division of Wildlife Research, in Washington, D.C. In 1984, planning began on obtaining a building for visitors at Patuxent, which had been discussed initially in the 1960s. Outside threats had been made to take over some of the land, but they were halted by the recognition that Patuxent was part of the refuge system. However, administrators realized that it was important that the public be aware of the value of wildlife research and the work of the USFWS in order to receive public support. A draft Public Use Plan for Patuxent dated 1985 states, "Overall Patuxent Wildlife Research Center has most of the key attributes of high potential for an excellent public use and educational program (as suggested in the 1984 FWS report to Congress…)." Given Patuxent's location near two major metropolitan areas, it was ideally situated to comply with "....the policy of the Service to encourage resource-oriented public use on its lands that will provide the broadest array of opportunities for visitor enjoyment and that will facilitate understanding and awareness for natural resources within Service care." The Section of Buildings and Grounds began a major reorganization to accommodate increased planning and land management responsibilities, and the first facility manager was hired in 1986.

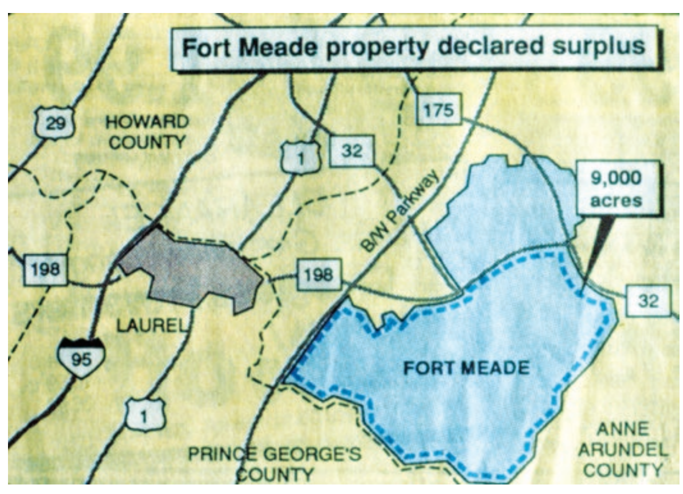
In August 1987, Mr. Harold J. O'Connor became director of Patuxent. Mr. O'Connor was the first director with experience in the management of national wildlife refuges, and he was also a member of the Senior Executive Service. One of Mr. O'Connor's first efforts was to obtain funding for the Visitor Center, which was being planned by his predecessor. Fifteen million dollars was obtained from Congress for this project, which evolved into a National Wildlife Visitor Center covering all wildlife research of the USFWS. The building was officially dedicated and opened to the public in October 1994, and has extensive exhibits depicting the wildlife research of the USFWS throughout the world. Researchers within and outside the Service are still conducting many of these research activities. Several support groups were established to help with fund raising and volunteer staffing of the Visitor Center, including the Prince George's County Foundation and the Friends of Patuxent.

In 1988, Patuxent staff prepared a second master plan. The new plan stated that the mission of Patuxent "has remained unchanged since the submission of the original Master Plan report. It is essentially the same as for the overall U.S. Fish and Wildlife Service." A later mission statement for Patuxent prepared in 1992 specifically included education and public use as important activities. This was a major change in the mission of Patuxent, but was responsive to public-use policies for the National Refuge System.

Several major rehabilitation projects involving impoundment control structures were undertaken under Mr. O'Connor's direction. New experimental pens and ponds were constructed and the appearance of the grounds around the buildings was improved. Many dignitaries, including U.S. Senator Paul Sarbanes and U.S. Representative Steny Hoyer, attended a major celebration of Patuxent's 50th anniversary on June 3, 1989. Senator Sarbanes, during his address, referred to the green forests of Patuxent as the "lungs of the Baltimore/Washington region."

Management of the wetlands and meadows became a formal activity with the implementation of impoundment and meadow management plans in 1989. A public fishing program in Cash Lake from June to October each year was initiated in 1991. A refuge biologist was hired to oversee all resource management activities, and the first refuge manager was appointed in 1992. These activities reflected the increased emphasis being placed on refuge management functions.

In 1991, 7,600 acres of land in Anne Arundel County that previously had been part of Fort George G. Meade, immediately adjacent to Patuxent to the north, were transferred to Patuxent because of the Military Construction Appropriations Act (U.S. Public Law 101-519). The U.S. Army, under the Base Closure and Realignment Act (U.S. Public Law 100-526), had declared the land excess. The transfer was based on the recommendations of a broad-based Fort Meade Coordination Council that had extensively studied the options and voted unanimously for the transfer. The transfer document specified that the intended priority uses of the property were preservation of the land, wildlife research, and compatible public use. In addition, the transfer document stated that the Secretary of the Interior "shall provide for the continued use of the property by Federal agencies to the extent such agencies are using it on the date of the enactment of this act." Some of these activities were not compatible with wildlife and would not have been allowed on Federal refuges without the added wording. An additional 500 acres, including four softball fields, were transferred to Patuxent in 1992. These transferred lands are now called the Patuxent North Tract.



Map included in newspaper article on surplus Fort Meade lands, Maryland, 1991. Reprinted with permission from The Baltimore Sun. All rights reserved.

Patuxent Visitor Contact Station on North Tract, Patuxent Wildlife Research Center, Laurel, MD, 1992. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

The acquisition of these lands added the responsibilities of a major deer-hunting program (bow, gun, and muzzle-loader) and increased public use and education. Other existing natural resource programs, including fishing, trapping for furs, and small-game hunting, were continued. Approximately half of the existing firing ranges continue to be used by defense and law-enforcement personnel for training under special-use permits with the National Security Agency and the U.S. Secret Service. Sport shooters under a special-use permit also used a trap and skeet range with a Goddard Space Flight Center shooting club. The range was later closed owing to concerns of lead poisoning, and study and remediation of lead contamination of the soil were conducted. A large, modern equestrian center was run by the U.S. Army's Civilian Welfare Agency under a permit issued by Patuxent. The stable closed in 2004 at the direction of the Fort Meade commander.

A Visitor Contact Station was constructed in 1993 on the new land to control public-use activities. This building was funded in part by the Prince George's County Parks and Recreation Foundation, which was later instrumental in the establishment of the Friends of Patuxent, a 501(c)(3) refuge support organization. Minimal USFWS staff and volunteers operate the contact station, with occasional part-time support from USFWS law-enforcement personnel.

In 1990, when the major land transfer from Fort Meade was imminent, the Regional Director of Research and Development for the USFWS stated that no research funds would be used for management of the newly acquired lands. Administrators at Patuxent, therefore, were required to seek alternative funding for these activities. The extensive hunting program conducted at the North Tract of Patuxent was initially conducted through Fort Meade, but Patuxent assumed responsibility for the program after the transfer. The refuge initially issued a special-use permit and then entered into a Cooperating Association Agreement with a group of hunters who formed the Meade Natural Heritage Association (MNHA), which continues today (2016) to assist with day-to-day operations of the hunting program. MNHA assesses a permit fee for all hunters who are allowed to use the area after they have taken and passed the gun and (or) bow safety and proficiency training program.

Hunter fees are used to pay several employees, who manage daily hunting from the Hunting Control Station. Some remaining funds have thus far been put back into the Patuxent North Tract for erosion control, wildlife management, and other projects. Expenses borne by Patuxent for the hunting program are mainly for part-time salaries of law-enforcement personnel during the hunting season plus administrative support and oversight. The original directive from the Regional Director of Research and Development was subsequently changed, and Patuxent was authorized to spend $75,000 of research funding in fiscal years 1992 and 1993 to operate the North Tract.

The increased activities related to the Visitor Center and the increased use of public lands in the early 1990s exacerbated staffing problems at Patuxent and increased overhead expenses. The center's staff was concerned about the lack of additional funding for administering the North Tract property, as well as the increased staff time devoted to developing the Visitor Center. As a result, in 1992 the USFWS director decided to transfer the administration of the new Fort Meade lands (North Tract) (8,100 acres) and the Visitor Center lands (South Tract) (2,000 acres) from Research Region 8 to the Division of Refuges in geographic Region 5. This transfer was to be effective in October 1993. Patuxent research staff would maintain control of the Central Tract (2,700 acres), where traditionally the researchers had been located and most of the on-site research had been conducted. Research staff would also still be responsible for management and public use on Central Tract lands. This decision received a mixed reaction from Patuxent employees, however, because there was no indication that increased funding would be forthcoming.

Transfer to National Biological Survey and then to U.S. Geological Survey

In March 1993, the DOI, headed by Secretary Bruce Babbitt, announced plans to form a new National Biological Survey (NBS) that would combine all biological research and monitoring within DOI into one bureau, separate from existing management bureaus. Opinion was divided on whether lands associated with Patuxent would be staying with the USFWS and be managed by the Division of Refuges or be transferred to the new NBS.

In November 1993, all research staff, many refuge staff, and several sections of the Office of Migratory Bird Management were transferred to the NBS. The new NBS organization also resulted in the transfer to Patuxent of one research unit of the National Park Service and all USFWS staff assigned to the Smithsonian Museum of Natural History. Although Patuxent administered 10 field stations in late 1993, realignment in the new NBS reduced the number of field stations to 4 in late 1994.

All lands and buildings of Patuxent continued to be officially controlled by the USFWS and within the Northeast Region 5 refuge organization. The actual maintenance of the buildings and management of the lands remained under the control of the director of Patuxent and his staff. This arrangement, in principle, provided protection of the land under all regulations and policies of the National Wildlife Refuge System, but gave maximum flexibility for use of the land for research purposes. This arrangement between the USFWS and the NBS was approved by Under Secretary of the Interior George Frampton, Jr., and was commonly called the Frampton Agreement.

On October 5, 1993, the Patuxent director announced a new strategic plan, which was to guide Patuxent's activities in the NBS. The plan marked the beginning of the process to align Patuxent's organization more closely with the NBS structure, which included major initiatives in surveying and monitoring habitats and populations and in transferring information and technology.

The primary mission of Patuxent as stated in the strategic plan was "to conduct biological studies in response to programs and priorities of the National Biological Survey (NBS) to support land and resource managers within the Department of the Interior. The Center will operate a National Biological Research area as an outdoor laboratory and operate the NBS National Wildlife Visitors [sic] Center for the advancement of environmental education and biological science." A major change in the new mission of Patuxent in NBS was a reduced geographic responsibility to only the Eastern Ecoregion and a shift away from national and international initiatives. In May 1994, the name of the Patuxent Wildlife Research Center was changed to Patuxent Environmental Science Center. In late 1994, the name of the NBS was changed to the National Biological Service to address several concerns, including the assertion that new research was not supporting historical "customers."

In March 1995, Patuxent's director, Mr. O'Connor, retired from Federal service after 35 years. Dr. James A. Kushlan became director in late 1995 and, because of circumstances within the Federal government, Patuxent endured a disheartening period when budgets were cut and 26 personnel were officially relieved of their services (reduction in force). The Branch concept (three main groups: migratory birds, endangered species, and environmental contaminants) was abandoned and all research was placed under the control of a chief scientist. In the spring of 1996, the name "Patuxent Wildlife Research Center" was restored. In October 1996, the NBS was terminated and all research staff became part of the Biological Resources Division of the U.S. Geological Survey (USGS). Refuge staff returned to the USFWS under the Northeast Region (Region 5). The research operation (USGS) continued to be known as the Patuxent Wildlife Research Center, whereas the land ownership, management, and public-use operations were under the historical name of Patuxent Research Refuge. Each entity had its own administration and management, but they worked together to support Patuxent missions.

A Comprehensive Science Planning Process, which included five themes that overlap the scientific activity areas chosen by the Biological Resources Division, was developed under Dr. Kushlan's leadership. The new mission for Patuxent was "to excel in wildlife and natural resource science, providing the information needed to better manage the Nation's biological resources."

In 2001, Dr. Kushlan resigned his position as director of Patuxent Wildlife Research Center; later that year, Dr. Judd A. Howell became the new director. Dr. Howell conducted a review of the organization and made changes following guidelines from headquarters that provided more program managers and more accountability from the Patuxent Wildlife Research Center staff and activities. Research staff was consolidated into Gabrielson Laboratory and a rented building at the Beltsville Agricultural Research Center. In spite of the division into two agencies, Patuxent's staff was optimistic that problems with facilities and responsibilities would be resolved, and they continued to work closely together. A joint Facilities Modernization Program was developed over the years to address the future facilities and infrastructure needs of the agencies.

In 2009, Dr. Gregory Smith assumed the position of director of Patuxent Wildlife Research Center. During this period, due to economic recovery programs (American Recovery and Reinvestment Act) throughout the United States, Patuxent was involved in the removal of some buildings and the planning of construction of new buildings. Dr. Smith led this initiative in close coordination with Mr. Bradley A. Knudsen, manager of the Patuxent Research Refuge. The refuge was going through a major comprehensive planning process, so the timing of the activities complemented each other. Patuxent made plans for an addition (annex) to Gabrielson

Laboratory that would greatly increase the ability of the research facility to continue with its research mission. The USFWS continued planning for new facilities, some of which would accommodate USFWS personnel from other facilities, especially the Chesapeake Bay Program, now located in rental space in Annapolis, MD. In 2014, Dr. Smith died while on official travel in China. Former director Dr. Judd A. Howell volunteered to fill the director position temporarily. A new director, Dr. John B. French, was appointed on May 26, 2015.

From a humble beginning with 2,670 acres of land in 1936, Patuxent has increased in size over its 80-year history to the present (2016) 12,841 acres. Much of the early land development was done under the direction of a superintendent, Dr. Morley. Nine research directors have succeeded Dr. Morley in supervising the research program; most of them were in charge of land development and maintenance. In 1994, however, all land-management activities came under the jurisdiction of the refuge manager under the USFWS, with the research program being placed in the USGS. The Patuxent Wildlife Research Center and the Patuxent Research Refuge are closely related, and the facility has operated in most cases as one unit. After more than 80 years, the staff, collaborators, and friends around the world simply refer to this facility, with pride and respect, as "Patuxent."

References Cited

Allen, D.L., 1949, The farmer and wildlife: Washington, D.C., Wildlife Management Institute, 82 p.

Allen, D.L., 1954, Our wildlife legacy: New York, Funk and Wagnalls, 422 p.

Crissey, W.F., 2006, A life like no other—The autobiography of Walter F. Crissey: Bloomington, IN, iUniverse, Inc., 468 p.

Hotchkiss, Neil, and Stewart, R.E., 1947, Vegetation of the Patuxent Research Refuge, Maryland: American Midland Naturalist, v. 38, no. 1, p. 1–75. [Also available at http://dx.doi.org/10.2307/2421630.]

McGilvrey, F.B., and Uhler, F.M., 1971, A starling-deterrent wood duck nest box: Journal of Wildlife Management, v. 35, no. 4, p. 793–797. [Also available at http://dx.doi.org/10.2307/3799789.]

Morley, L.B. [sic], 1948, Early history of Patuxent Wildlife Research Center (circa 1948): U.S. Geological Survey, 74 p., accessed October 3, 2011, at http://www.pwrc.usgs.gov/history/cronhist/Morley4.pdf.

Perry, M.C., Kangas, P., and Obrecht, H.H., III., 2000, Creating and managing wetland impoundments to provide habitat for aquatic birds, *in* Comin, F.A., Herrera, J.A., and Ramirez. J., eds., Limnology and aquatic birds monitoring, modelling and management: Universidad Autonoma de Yucatan, International Symposium on Limnology and Aquatic Birds, Monitoring, Modelling, and Management, 2nd, Merida, Mexico, November 24–27, 1997, p. 261–279.

Stewart, R.E., Cope, J.B., Robbins, C.S., and Brainerd, J.W., 1952, Seasonal distribution of bird populations at the Patuxent Research Refuge: American Midland Naturalist, v. 47, no. 2, p. 257–363. [Also available at http://dx.doi.org/10.2307/2422265.]

Warbach, Oscar, 1958, Bird populations in relation to change in land use: Journal of Wildlife Management, v. 22, no. 1, p. 23–28. [Also available at http://dx.doi.org/10.2307/3797292.]

Snowden Hall, Patuxent Research Refuge, Laurel, MD. Photo by Bureau of Biological Survey.

Early Avian Studies at Patuxent

Chandler S. Robbins

When I arrived at Patuxent Research Refuge (Patuxent) in Maryland in the spring of 1943, I was amazed to find that the refuge, barely 6 years old, had already been surveyed with a 100-meter (m) (325-foot [ft]) grid. The presence of permanent survey markers every 100 m and trails throughout the grid provided an ideal situation for recording the precise position of all wildlife observations. The grid system was so well coordinated with construction of the laboratory buildings that wherever a grid line passed through a building, a marker showing the passage of the line through the building was inserted in the brick wall. Wherever a grid line crossed the Patuxent River, an extra survey marker was placed on the riverbank, but most of these river-crossing posts were washed away in subsequent floods.

I was impressed with the expertise and dedication of the young professional staff. Superintendent Leland Morley and veterinarian Don Coburn had veterinary degrees, but I do not believe a single staff member at that time had a Ph.D. degree, unless it was a chemist. I was also impressed with the national collections of bird and mammal skins, reptiles and amphibians, and seeds and pressed plants that were being used to identify stomach contents.

Four major programs of the former Bureau of Biological Survey had been moved from Washington, D.C., to Patuxent (which at that time had a Bowie, MD, address): the Bird Banding Laboratory and the Bird Distribution and Migration Files and species maps, under Frederick C. Lincoln; the Mammal Files, including bat banding records, under Hartley H.T. Jackson; and the Food Habits records. The bird and mammal offices were in the Bird and Mammal Laboratory (later called Nelson Laboratory), the Food Habits staff and all the specimen collections were in the Food Habits Laboratory (later referred to as Merriam Laboratory), and the veterinary staff was in the Disease Laboratory (which became Henshaw Laboratory).

The Biological Survey's Division of Economic Ornithology and Mammalogy had been conducting food habits studies of birds and mammals since 1885 to determine which species were useful to agriculture. By 1943, most of the effort was devoted to teaching biologists from various states the techniques of examining stomach contents and identifying the fragments of insects, arthropods, seeds, and other material. When Congress suspended all funding for food habits studies in 1943, this work suddenly stopped. The stomach material that had been examined was offered to the states from which it had come, but all the examination cards were retained at Patuxent.

U.S. Biological Survey plot marker at Patuxent Research Refuge, Laurel, MD. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Bird Banding

The Bird Banding Laboratory

Shortly after passage of the Migratory Bird Treaty Act with Canada in 1916, it was determined that bird banders should be licensed under Federal permits, so the banding program was moved from the auspices of the American Bird Banding Association to the U.S. Biological Survey in 1920 under the supervision of Fred Lincoln. When the program was moved to Patuxent in 1936, Fred Lincoln and his secretary, Myra Putnam, retained their offices in Washington, D.C., but Mr. Lincoln made frequent visits to Patuxent, where May Thacher Cooke (daughter of the late Wells W. Cooke of the Biological Survey) was in charge of the daily operations.

My first assignment at Patuxent was as a biologist in the Banding Laboratory, checking incoming schedules and coding return records for keypunching. I was already familiar with the species codes (American Ornithologists' Union [AOU] numbers) and most of the other codes from my previous 6 years as a bird bander. The principal codes I had to look up on the code board were IBM Corporation's (IBM's) three-digit numerical code for North American localities (such as 717 for Patuxent); we were not using latitude and longitude in those days. In 1943, we did not yet have a keypunch or a card-sorting machine.

The only other people in the Banding Laboratory in the 1940s were processing clerks Margery Stewart and Lois Horn, and mail carrier and band issuer Russell Carpenter. Each morning Russell stopped at South Interior Building to pick up the mail on his way to work because the bands carried a Washington, D.C., address. After May Cooke retired and Fred Lincoln was moved to the Chicago office, John Aldrich at the National Museum of Natural History handled administrative matters for the Banding Laboratory and I continued as biologist. I had been concerned about the future of the songbird-banding program because our staff was insufficient for the workload and the waterfowl people insisted that processing of waterfowl records should take priority. We were accumulating a sizable backlog of unprocessed songbird records. When I heard that we were about to advertise a position for a banding chief, I telephoned Seth Low, Refuge Manager at Salt Plains National Wildlife Refuge in Oklahoma, whom I had known when he worked at the Austin Ornithological Research Station on Cape Cod, MA, and urged him to apply because of his interest in songbird banding as well as his lengthy experience as a waterfowl bander. Seth was offered and accepted the position, along with all its related problems, but songbird banding survived.

Ruth Richards worked part time with the Bird Distribution and Migration program, sending and acknowledging the 2-in. × 5-in. observation cards and assembling certain records for publication. She spent the remainder of her time working with Hartley Jackson's mammal files.

Chan Robbins banding songbirds, Patuxent Research Refuge, Laurel, MD, 1948. Photo by U.S. Fish and Wildlife Service.

Songbird Banding

Leonard Llewellyn, Royal Stewart, and R.N. Crack were the first to band a few Patuxent birds in 1940, 1941, and 1942. From 1943 to 1946, Robert Stewart, James Cope, John Brainerd, and I trapped and banded thousands of songbirds using conventional traps baited with grain or dripping water. We recorded the grid-cell number of each bird banded in order to study movements through the recaptures. Father Fabian Kekich at Catholic University in Washington, D.C., had been having amazing success in baiting migrating warblers with dripping water in top-opening traps. When he moved to another location he kindly gave us all his traps, but we could not match his wooded hilltop in an urban location and never had the concentration of migrating warblers that he enjoyed.

In 1959, Donald Stamm, David Davis, and I began a breeding bird study in deciduous forest in and near the flood plain of the Patuxent River (3600 block of the Patuxent grid), which continued through 1972. For 6 or more days each season, birds captured in mist nets were identified, banded, and released; the date, time, and location of all initial captures and recaptures were recorded. This study was among the first to use capture-recapture methods to estimate population size for various bird species (Stamm and others, 1960).

Raptor Banding

Ira Gabrielson had been impressed by the high density of hawks and owls at Patuxent, as had local falconers. John Hamlet, in particular, was a frequent visitor who helped us use various techniques to trap and band a few hundred resident and migrating raptors. We were most successful with the Verbail pole trap and operated these night and day, checking at sunrise and several times during the day in 1943–45. Nestling red-shouldered hawks (*Buteo lineatus*) were banded each year, and especially in 1947 when Burt Taurman was a summer student. Of 107 nestling red-shoulders banded in 1947 in stream valleys in and near Patuxent, 9 were shot and another was found dead in the next 2 years, all in Maryland.

Operation Recovery

Shortly after Oliver L. Austin, Jr., introduced the use of Japanese mist nets to North America and banders began flocking to coastal beaches to capture grounded migrants, I joined Massachusetts Audubon Society scientists James Baird, Aaron Bagg, and John Dennis (Baird and others, 1958) in promoting a cooperative coastal banding program during fall migration. We called it Operation Recovery with the expectation that, with enough songbirds being banded at coastal sites, we should be able to recapture banded birds farther south in the same season and determine how far they were flying in a single night. Furthermore, to participate in the study, banders were required to keep a record of the number of net-hours of effort each day and to weigh their birds, record wing chord, and determine age and sex when possible. This was the first time banders had ever been required to keep track of banding effort, to weigh their birds, or to make a special effort to determine age and sex. This was just before I published my key to aging and sexing of wood warblers in fall (Robbins, 1964). To our surprise, the first recaptures of banded birds occurred north of where they had been banded, showing that many migrants routinely wander northward before initiating their southward migration.

Many other surprises followed. Considering only those from Maryland, on September 17, 1965, Operation Recovery captured at Ocean City the first hybrid between a northern waterthrush (*Parkesia noveboracensis*) and a blackpoll warbler (*Dendroica striata*) (Short and Robbins, 1967). Four western wood-pewees (*Contopus sordidulus*), the first for the Atlantic Coast, were caught at Ocean City on four September 1961 dates; a western tanager (*Piranga ludoviciana*; first Maryland record) was banded on October 21, 1962; a rufous hummingbird (*Selasphorus rufus*; first Maryland record) was banded on September 12, 1963; and a Hammond's flycatcher (*Empidonax hammondii*; first East Coast record) was captured on October 9, 1963. More first-year birds were captured at coastal locations, where survival rates were lower, than at inland ones (Robbins and others, 1959).

Operation Recovery also collected thousands of ticks from the ears of migrating birds (Clifford and others, 1969). When an impatient bander complained to the Director of the U.S. Fish and Wildlife Service (USFWS) that I was late in publishing a summary of results, the Director wrote me that we should not be studying fall migration of songbirds and I should cease immediately. Therefore, the large, bound tabulations of weights and wing chords of North American fall migrants lie unpublished in the Patuxent library. Several of the coastal banding stations eventually became full-time bird observatories, and I believe that one of the great contributions of the Operation Recovery program was the training of hundreds of banders in aging and sexing fall migrants and in recording their banding effort.

Evolution of the Bird-Banding Record Card

Houston and others (2008), in "History of 'computerization' of bird-banding records," discussed successive changes in the design of the bird-banding schedule, but we authors neglected to mention the changes that had been made to the design of the return card. The cards are now history. Essentially all were destroyed when we made the transition to totally electronic files.

Prior to 1929, a printed 3-in. × 5-in. card was used for each recapture and each recovery record of a banded bird. Beginning in 1929, each record was placed on an 80-column, 3.25-in. × 7.375-in. punch card on which the vital banding and recovery data were handwritten in labeled spaces in the first 36 columns, and the remaining columns were reserved for future keypunching of the same information. The card was reprinted, unchanged, in October 1939 and September 1941. In April 1950, the handwritten portion was redesigned to add an eighth digit to the band number, to include codes for

Jerry Longcore capturing woodcock with mist nets, Milford, ME, 1998. Photo by Daniel McAuley, U.S. Geological Survey.

hand-reared and sick or injured birds, to change the position of categories in the handwritten portion of the card, and to provide for the permit number, but the punch holes were not altered except to replace "FY Rec'd" with "Elapsed Time." In an August 1953 revision, the card was made more user friendly, providing for easy reading of an "interpreted" card; "Operator" was finally replaced by "Permit No," "Schedule No." was omitted, and the handwritten portion of the card was neatly rearranged with banding information at the top and recovery information below.

In January 1955, the handwritten portion of the card disappeared, the positions of all the columns were changed, and new categories were added for "Status," "Letter Received Date," and "Previous Reports." "Latitude" and "Longitude" were substituted for the alphabetical abbreviations of "Where Banded" and "Where Recovered." For the first time, "U.S. Fish and Wildlife Service" and "Canadian Wildlife Service" appeared on the punch card. Another revision in July 1959 added columns for "Additional Information," "Dir. Banding," "Dir. Recovery," "Who Reported," and "Hunting Season." The last seven columns of the card remained vacant.

Other Bird Monitoring

Initial Avian Studies on the Patuxent Grounds

The only avian publication that originated at Patuxent prior to 1943 was a Christmas Bird Count (49 species, 2,475 individuals). This count was conducted within the Patuxent boundaries on December 23, 1941, by bird enthusiasts John Aldrich, Leo Couch, Lucas Dargan, Herbert Deignan, John Hamlet, Neil Hotchkiss, Phoebe Knappen, Leonard Llewellyn, Alexander Martin, Franklin May, George Petrides, Robert Smith, Robert Stewart, and Francis Uhler. We resumed Christmas Bird Counts in 1943, and they are still conducted annually within the original 2,670 acres as part of the Bowie, MD, 7.5-mile (mi)-radius circle.

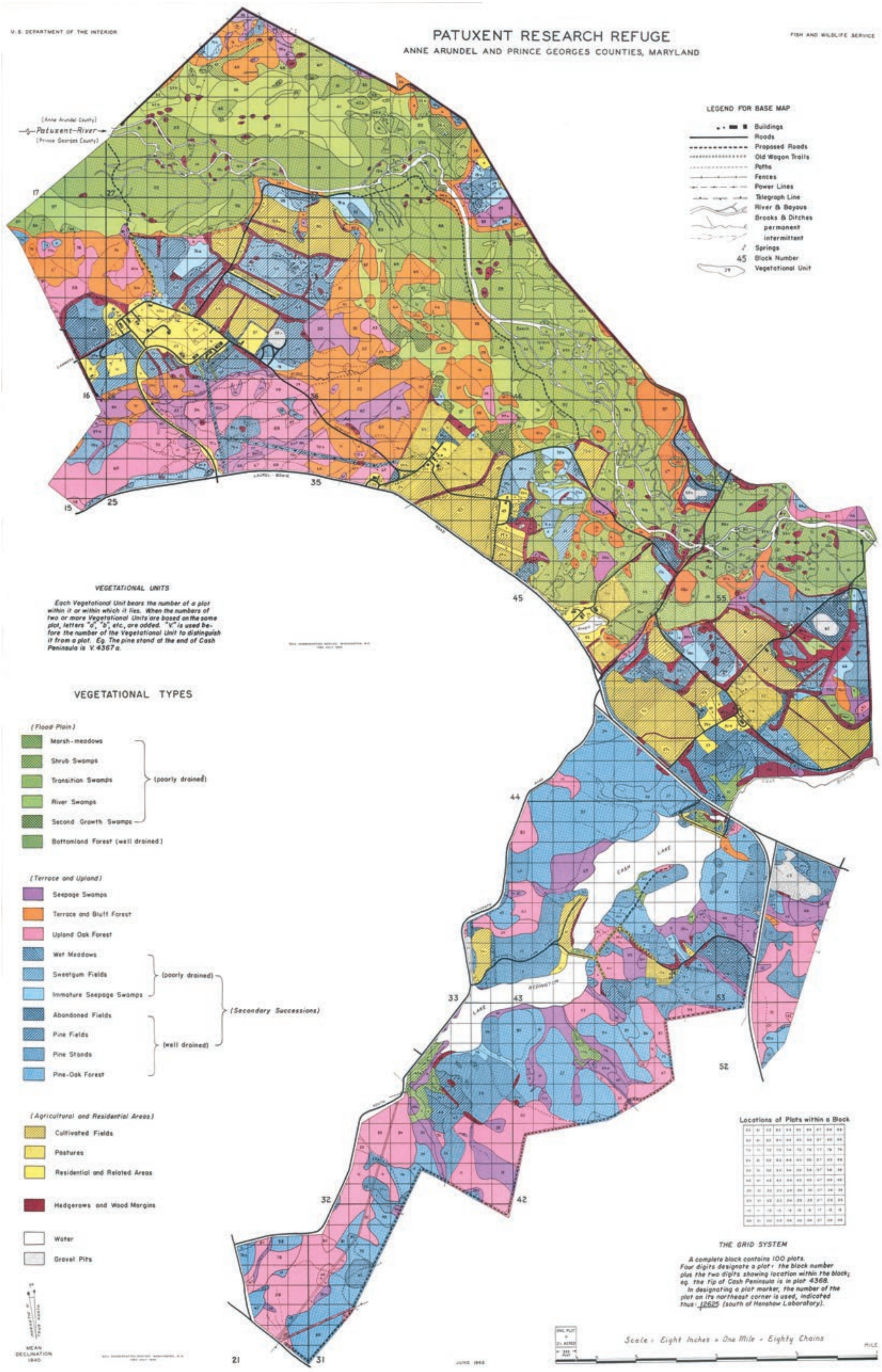
At the same time, Patuxent staff members (primarily Ira Gabrielson, Clarence Cottam, Francis Uhler, and Arnold Nelson) had been conducting a carefully controlled Christmas count in a 20-year study (1927–46) at Port Tobacco in Charles County, MD, to determine whether changes in winter bird populations could be detected if an area was carefully covered the same way on foot each year by (primarily) the same four people. One year, I was invited to be one of the four participants, and was shocked to find that they would not accept observations unless the bird was identified by sight. If a jay or an owl was heard, or if a woodpecker called, it could not be counted unless it was identified by sight. At the end of the 20 years, the observers did not detect changes over time and determined that their results were not worth publishing. If they had continued a few more years, they would have noted major changes in populations of eastern bluebirds (*Sialia sialis*), Carolina wrens (*Thryothorus ludovicianus*), loggerhead shrikes (*Lanius ludovicianus*), and several other species.

The Vegetation Map and Documentary Bird Surveys

A colored vegetation map of the entire refuge was completed in 1943 by observers walking the grid lines, pacing the distance to each change in habitat, and recording the results on 1-kilometer (km) (0.6-mi) field maps. The next major task was for biologists Robert Stewart, John Brainerd, James Cope, and me to hike the same grid lines during the 1943 nesting season, recording on the 1-km sectional maps the location where each bird was detected. The entire refuge was covered three times: in April for raptor and crow nests, in May for woodpeckers and early-nesting Passeriformes (passerines), and in June for most other nesting species. Special trips were made in July to areas where the late-nesting American goldfinch (*Carduelis tristis*) and cedar waxwing (*Bombycilla cedrorum*) were found. These detections were then transferred to black-and-white copies of the vegetation map to show the distribution of each species by habitat.

In the next two winters, the same four observers mapped the winter distribution of each bird species. Our awareness that winter populations are much more variable from year to year than are breeding populations explains the additional year of mapping in winter.

Botanist Neil Hotchkiss surveying plants, Patuxent Research Refuge, Laurel, MD, 1946. Photo by Francis M. Uhler, Patuxent Research Refuge.



Colored vegetation map of original 2,670 acres at Patuxent Research Refuge, Laurel, MD. Illustration by U.S. Soil Conservation Survey, Washington, D.C., 1945.

To continue studying changes in Patuxent bird populations, we conducted a "population fluctuation census" that tracked population changes by habitat weekly (twice weekly during the peaks of the spring and fall migrations) throughout 2 years over a 2.6-mi transect in the center's headquarters area. The transect began in the historic pear orchard of the Snowden family just north of Snowden Hall, proceeded due west through Ralph Nestler's quail pens to the west boundary fence, then extended north parallel to the fence into the flood plain, then east for nearly 1 mi through the flood plain, then south through the large fields to Snowden Brook, and west up the Snowden Brook valley to the new Entrance Drive. This survey was run by three observers walking parallel paths 100 m (325 ft) apart and keeping records by habitat. Results of the breeding and winter counts, population changes throughout the year, and a detailed species account for the 229 species that had been recorded at the refuge were published by Stewart and others (1952), but the habitat records from the population fluctuation census have never been published. Bob Stewart took the notebooks with him when he moved to the Northern Prairie Wildlife Research Center (Jamestown, ND), intending to publish the results; after his death in 1993 the notebooks were returned to Patuxent, but other priorities have prevented their publication.

Territory Mapping

The next field research was selecting study sites typical of each of the major Patuxent habitats (flood-plain forest, oak-beech river terrace forest, Virginia pine (*Pinus virginiana*) forest, upland oak forest, and abandoned field) and conducting spot-mapping censuses in each. From 8 to 40 or more census trips were made to each site using the method of Williams (1936), except that special emphasis was given to recording simultaneous registrations of males in adjacent territories. From repeated census trips to the same site, we could determine the probability of detecting each species on a single visit; probabilities ranged from 36 percent for worm-eating warbler (*Helmitheros vermivorum*) to 81 percent for hooded warbler (*Setophaga citrina*). I helped Donald Thatcher of Washington, D.C., Audubon Society to set up a long-term census site in the Potomac River flood plain for comparison with Patuxent, and Joan Criswell, one of my students at the U.S. Department of Agriculture Graduate School (now Graduate School USA) in Washington, D.C., set up a site in nearby Rock Creek Park that was censused for many years and was the first such site to demonstrate the decline in wood thrushes (*Hylocichia mustelina*) and other Neotropical migrants (Briggs and Criswell, 1979).

Nest Record Cards, 1940s–50s

Bob Stewart designed a two-sided 3-in. × 5-in. nest record card with space for species, location, habitat, contents, and observer name on the front and space for 10 subsequent observations on the back (Stewart and Robbins, 1958). The same card was used to record historical information from throughout Maryland. The file now contains tens of thousands of records that I hope can be digitized someday. This file was the basis for the nesting paragraphs in the first Maryland/D.C. breeding bird atlas. The second atlas contained primarily generalized nesting information from out-of-state sources.

Field-Testing of the Mourning Dove Call Count Procedures

Harold Peters and Leonard Foote had been designing procedures for a national call count survey of breeding mourning doves (*Zenaida macroura*). The plan was to have twenty 3-minute roadside stops 1 mi apart, but the best starting time was undecided. They planned to do final field testing in Georgia and asked Allen Duvall and me to run sample routes in Maryland and Pennsylvania, where the twilight time is longer and where early-morning traffic might be a greater problem. Their conclusion and ours were the same: that the best results were obtained when the survey started 30 minutes before sunrise. However, when we put the starting time to a vote, it was 3 to 1 in favor of starting at sunrise "because you can't ask the State biologists to get up that early." Now, 45 years later, we still begin the survey at sunrise.

"The DDT Years," 1945–49

On June 5, 1945, at the height of the breeding season, a 117-acre tract of the forested refuge just downstream from Duvall Bridge was sprayed just above treetop level with 1 pound of dichlorodiphenyltrichloroethane (DDT) per acre (Robbins and Stewart, 1949). We had insisted that this site, where the Patuxent River leaves the refuge, should be the site of the aerial spraying, in order not to contaminate the rest of the refuge. A study site had been established in the center of the sprayed area, and two control sites had also been established, one adjacent to the sprayed area and about 1 mi upstream. The bird crew (Stewart, Cope, Brainerd, and I) conducted breeding bird censuses in all three study plots before and after spraying. Except for the American redstart (*Setophaga ruticilla*), a treetop feeder, no change in breeding population or in hatchability of eggs or survival of nestlings could be demonstrated. Subsequent aerial sprayings of 2 pounds of DDT per acre in May or early June of 1946 through 1949 caused substantial declines immediately after spraying only in the American redstart. It was determined that most of the spray was captured by leaves in the canopy, so little of it reached the understory where many of the birds were foraging and nesting (Robbins and others, 1951).

In 1947, a 90-acre area of scrub forest on the nearby USDA Agricultural Research Center that was recovering from a 1942 forest fire was sprayed with 5 pounds of DDT per acre to study effects of DDT in an open environment. Bird populations were studied in a 30-acre plot in the center of the sprayed area and in a 30-acre unsprayed plot 0.5 mi away. Of the five most common species in the sprayed area, the common yellowthroat (*Geothlypis trichas*), prairie warbler (*Setophaga discolor*), and house wren (*Troglodytes aedon*) were reduced 80 percent and the eastern towhee (*Pipilo erythrophthalmus*) was reduced apparently 65 percent, whereas there was no appreciable change in number of yellow-breasted chats (*Icteria virens*).

In the meantime, DDT studies based on manual applications on active bird nests were conducted to determine whether eggs and young would survive (Mitchell and others, 1953). With a nesting population of color-banded eastern bluebirds and house wrens available, I could not resist the temptation to follow two populations over a 3-year period. The bluebirds were especially interesting in that both adults and young returned to nest at the same site year after year. Soon most of the birds were related to each other. At a meeting of the North American Bluebird Society, I shocked the membership by showing that a 1-year-old male bluebird was mated to his grandmother. I started a long-term study of nesting barn swallows (*Hirundo rustica*) in the Hance Farm barn, but it was terminated in the second year when the barn was boarded up.

Studies of Nocturnal Bird Migration

Patuxent researchers installed a U.S. Navy (Navy) radar system outside Nelson Laboratory in 1945 in the hope of detecting songbirds flying at night, but it turned out to be the wrong type of equipment and I could not detect anything smaller than the Chesapeake Bay Bridge, so we had to resort to less technical methods.

Bob Stewart and I made many trips to the Washington Monument on cloudy, moonless evenings in the autumns of 1945 and 1946 to study migrating birds that struck the monument in the hours before midnight, while the spotlights were on. The birds were attracted to the monument by the spotlights; they tried to fly to one side or the other, but were swept by the wind against the backside with enough force to produce concussions, and they fell to the ground. We got permission from the Park Police to drive our vehicle to the base of the monument so we could immediately put the birds in cages. Any survivors were released the next morning at Patuxent. We made study skins of the casualties. We learned many of the night call notes (which were generally different from the familiar diurnal calls) by listening to and watching the birds as they collided with the monument.

In a separate study, I joined 2,500 observers throughout North America in a cooperative study of bird migration organized by George Lowery and Robert Newman of Louisiana State University (Baton Rouge). They solicited observers to make all-night counts of birds flying across the face of the full moon. The birds were visible for only an instant as they crossed the moon, but the birds seen provide an index to the vast number that are unseen. The organizers had developed equations to translate the number of birds seen to the number that had crossed a 1-mi-long line centered on the observer, corrected for the latitude of each observer. On the night of September 22–23, 1953, using a wire recorder, I counted 2,188 birds flying overhead, which translated to 230,000 birds crossing a 1-mi-long line centered on my driveway. That was the highest count ever recorded in North America (Lowery and Newman, 1955).

Breeding Bird Survey

In the early 1960s, DDT was still widely used to control insects on college campuses, and each application resulted in distressed and dying robins and other songbirds. One woman in the Midwest was concerned about the future of songbirds in North America and wrote to inquire whether the loss of nesting birds on campuses across the country was sufficient to affect continental populations. I replied that at present, there was no continental survey that could answer that question, but I said I would give it some thought. We did have waterfowl surveys, but they did not reveal anything about songbirds. There were Federal game agents and State agents, but most of them had no experience with songbirds. The only hope would be to find enough trained bird enthusiasts who would be willing to conduct rigid surveys over a period of years.

I proposed a plan to the Maryland Ornithological Society (MOS) that could allow me to hand-pick qualified observers; assign 50 random roadside routes of 50 stops each, 0.5 mi apart, throughout the State; and have each observer run a “check route” that I had run in addition to his or her own assigned route. Jack Linehan offered to recruit observers for 10 Delaware routes as well, and all 60 routes were run successfully in 1965. The number of birds recorded on the 50 Maryland routes was 50,373, or an average of 1,007 individuals per route. The observers enjoyed the experience and were prepared to run the same routes the next year.

The next question was whether Patuxent would be willing to take the responsibility of running a national breeding bird survey program and whether Canada would be willing to join in. I explained the success of the 1965 trial to John Aldrich, my supervisor; told him of my plan to expand gradually across the continent in the next 3 years; and asked his opinion. His considered reply was, “Go for it—just so it doesn’t cost the government any money.” I had all the help I needed: a full-time secretary (Romell Decker); a full-time, experienced map expert (Ceil Nalley); a programmer (John McDaniel); plenty of keypunch time (during the lax banding-recovery period of summer); free phone service; and free mail. We needed only to design forms to use in the field, select random starting points for the survey routes, and draw the route paths. Tony Erskine was eager to act as my Canadian counterpart. The rest is history. My brother Sam had already started a State monitoring program in Wisconsin based on observer-selected sites in 1961, but he recognized the value of a randomly distributed sample, so he was glad to change to our random design.

Data Bank of North American Breeding Bird Censuses

In 1973, the USFWS began a program of computerizing breeding bird census data (Robbins, 1977). Initially, data from 1,939 census studies representing 801 different plots from 1937 to 1970 were coded and keypunched onto magnetic tape. Subsequently, data from 1971 to 1975 were added. Each plot was assigned a permanent number. A bound computer printout of this file can be found in the Patuxent library.

Winter Bird Survey of Central Maryland

The Winter Bird Survey (WBS) was designed to sample midwinter bird populations and to determine how well the Audubon Christmas count sampled year-to-year changes. The validity of the Christmas count had been questioned because the areas covered were selected rather than random, coverage was a mixture of walking and driving, and the number of hours of effort varied among observers. To control the coverage, each WBS observer walked a predetermined 8-km (5-mi) closed-circuit course in 4 hours, beginning at 7:30 a.m. The area selected for this study extended from Chesapeake Bay west to the base of Catoctin Mountain and from the Potomac River north to the Pennsylvania border. Location of counting areas was by a systematic sample, with one route located at the center of each 7½-minute U.S. Geological Survey (USGS) quadrangle. Each of the 40 routes was covered one morning per winter from January 15 to February 15. The method was tested in the Laurel quadrangle in the winter of 1968–69 by Patuxent staff. We compared the WBS results with those of the four Christmas counts made each year in the same geographic area. For most species, the WBS totals were higher than the Christmas count totals because the WBS counts were made entirely on foot; it was primarily the feeding-station birds that were found in higher numbers on the Christmas count. The close correlation between the two methods in 1970–74 indicated that Christmas count data for past decades might be a valuable index to population change, even though these data cannot in themselves be subjected to critical statistical analysis.

Woodcock, Snipe, and Clapper Rail Surveys

Most of the woodcock survey work was conducted on the breeding grounds in the Northeastern States and eastern Canada, but the reports were compiled and edited at Patuxent (Aldrich and others, 1952). Bob Stewart estimated the breeding population of American woodcock (*Scolopax minor*) at Patuxent to be 25 territorial males in 1942, decreasing to 21 pairs in 1943, 8 in 1947, and 9 in 1951. The large reduction from 1943 to 1947 was probably almost entirely due to "clearing in connection with farm wildlife experiments, but partly also from natural succession" (Stewart, 1952). Roadside routes in the Maryland suburbs were later abandoned because of traffic noise.

Initially there were no consistent common snipe (*Gallinago gallinago*) surveys, but snipe hunting could not be permitted on the Gulf Coast wintering grounds unless a USFWS biologist was conducting population studies on this species. Therefore, I established a cooperative winter survey program in the Southern States in 1953; banded snipe at winter concentration spots including coastal Florida, Mobile Bay, and Sabine Refuge in Louisiana (1950–55); and spent the summers of 1952–54 studying nesting snipe at Midgic Marsh in New Brunswick, Manitoulin Island in Ontario, and across upper northwestern Canada.

Bob Stewart (1952) studied clapper rails (*Rallus longirostris*) nesting at Chincoteague, VA, in 1950–51, and trapped and banded 940 of them. Hunters reported 10 recoveries (5 percent) from the 198 birds banded in 1950.

Geographic Variation in Bird Song

I had long been interested in geographic differences in bird songs. As a teenager, a neighbor (Ingraham, 1938) had given me a tuning fork and encouraged me to record the exact pitch of songs of wild birds. In New England, the ovenbird (*Seiurus aurocapilla*) says "tea'-cher, Tea'-cher, TEA'-CHER," as described in the field guides, but in other regions it says "teacher', Teacher', TEACHER'," and in Maryland it says "teach, Teach, TEACH." In all geographic regions, the increase in volume as the song progresses is diagnostic of the species.

In the summer of 1954, when I was studying snipe distribution across Canada at dawn and dusk, I used the long summer days to make tape recordings of bird songs to study differences in dialect from east to west. When it was not convenient for me to access my tape recorder and parabola, I carried a supply of index cards in my pocket to record the cadence (songs per minute), temperature, and locality of singing birds because I had not seen this information published previously. I tried for a series of 11 consecutive songs (10 intervals) from each bird. Patuxent biologist Sam Droege subsequently digitized this file.

Many more interesting experiences followed, including my long-term banding and population study of the breeding birds in a 90-acre plot in the Patuxent River terrace forest and the effect of forest fragmentation on nesting songbird populations in a random sample of 469 Maryland forests. I also trained Latin American scientists in bird census and banding techniques in nine Latin American countries. I returned to six Allegheny County forest study sites I had censused 50 years previously to conduct wind turbine studies, and I helped with the Breeding Bird Atlases in Maine, New Hampshire, Pennsylvania, Maryland, and West Virginia to demonstrate the need for habitat protection here at home.

Collaboration

Collaboration with the Audubon Society of the District of Columbia

In 1947, Bob Stewart, John Aldrich, and I collaborated with three Washington, D.C., Audubon Society members to produce their first “A Field List of Birds of the District of Columbia Region.” In 1951, Shirley Briggs and I edited their habitat pamphlet, “Where Birds Live: Habitats in the Middle Atlantic States.” I wrote their monthly season reports from 1946 to 1948 and their bimonthly reports from 1948 to 1949, as well as a Hawk Watch article for their “Atlantic Naturalist” journal in 1956.

Collaboration with the National Audubon Society

Shortly after Joseph Hickey wrote his “Guide to Bird-watching,” he and his wife, Peggy Brooks, were residing in Snowden Hall, while he used our Distribution and Migration files to compile a list of former breeding sites of the peregrine falcon (*Falco peregrinus*) and then used the banding files for a paper on survival rates of banded birds. Peggy had been editing the bird population studies (Christmas counts, breeding bird census, and winter bird population studies) for the publication “Audubon Field Notes,” and she was very concerned that National Audubon Society would discontinue publishing the breeding and winter population studies when she resigned because they were not making a profit on them. John Aldrich, Bob Stewart, and I believed that these studies, especially the breeding bird censuses, which had been published since 1937, were important, so we agreed to serve on an editorial board with a few other scientists if the National Audubon Society would continue the publication.

I ended up editing the breeding bird censuses from 1952 to 1966. The principal advantage to us of this collaboration was that it kept us in touch with serious bird population researchers throughout the United States and Canada, and these were the people I later recruited as State and Provincial coordinators when I launched the Breeding Bird Survey.

Collaboration with American Ornithologists’ Union

After Fred Lincoln retired, I was asked by Alexander Wetmore, Director of the Smithsonian Institution (Smithsonian), to update the range descriptions of the seabirds and shorebirds for the fifth (1957) edition of the AOU “Check-list of North American Birds.” I also became caretaker of the supply of back issues of the “Auk” (in the Nelson Laboratory attic), which had been Fred Lincoln’s duty as treasurer of the AOU. Back issues, as available, were distributed to U.S. and Canadian institutions; after that, the remainder was sent to the Smithsonian for their foreign exchange program. Another assignment was to compile the breeding and winter range descriptions and migration dates for the remaining volumes (warblers, blackbirds, finches, and sparrows) of A.C. Bent’s “Life Histories of North American Birds.”

Collaboration with other Conservation Organizations

I ran the Howard County mourning dove survey route for the Maryland Department of Natural Resources (DNR) from 1966 through 2008. I must admit that I would have been bored if I had recorded only the doves I heard and saw, so I recorded all species and reported only the doves to the DNR and the USFWS. The Howard County dove route had to be redrawn twice, first because of a permanent road closure and again because of traffic. The changes in route did not affect the dove counts, but did affect the counts of some of the songbird species. In 1982, I served on the DNR’s Monie Bay Estuarine Sanctuary Committee. I served on the Governor’s Executive Committee for Trees and Forests from 1992 to 1995, on the Regulations Review Team in 1991, and on the Belt Woods Advisory Committee during 1985–95.

I wrote the quarterly Season reports of bird observations for “Maryland Birdlife” from 1947 to 1977, and served as the MOS’s State president from 1952 to 1955, as editor of “Maryland Birdlife” from 1947 to 2014, and as an MOS trustee during 1961–2000. In 1968, biologist Willet T. Van Velzen and I published “Maryland Avifauna Number 2, The Field List of the Birds of Maryland” (44 pages), which shows updated migration and nesting dates.

I served as a trustee of the Bleitz Wildlife Foundation (1967–70) and Secretary of the International Bird Ringing Committee (1966–74), and was a member of the International Bird Census Committee (1966–87). Beginning with the International Ornithological Congress meeting at Oxford in 1966, I was the U.S. representative on the International Bird Census Committee (IBCC) and the European Ornithological Atlas Committee and also Secretary of the International Bird Ringing Committee. I participated in IBCC meetings at Oxford in 1966; Hilleröd, Denmark, in 1968; Ammarnäs in Swedish Lapland in 1969; Oosterbeek, Netherlands, in 1970; Warsaw in 1973; Szymbark, Poland, in 1976; Göttingen, Germany, in 1979; Lyon, Spain, in 1981; Giles, Buckinghamshire, United Kingdom, in 1983; Dijon, France, in 1985; and Helsinki, Finland, in 1987. These meetings kept me in touch with all the latest international thinking and planning on bird census and atlas studies.

I wrote a chapter for Robert Shosteck’s 1968 “Potomac Trail Book,” and Bob Stewart and I wrote the Maryland/D.C. chapter for Sewall Pettingill’s 1951 “Guide to Bird Finding East of the Mississippi.” Patuxent’s Earl Baysinger and I were on the three-member USFWS team that drafted the United

States/Soviet Union Migratory Bird Treaty using banding recoveries and the historic bird distribution and migration files. In 1976, we went to Moscow and Kiev to negotiate final details with our Soviet colleagues This treaty was unique in protecting not only the shared species, but also the habitats they required (https://www.fws.gov/le/pdf/MigBirdTreatyRussia.pdf, accessed December 17, 2015).

Cooperative Study of Hawk Migration

I had been intrigued by the regularity with which large numbers of migrating hawks were seen at Hawk Mountain, PA, and I thought there might be a more advantageous place than Monument Knob to intercept these flights in Maryland. Therefore, in the fall of 1949, I organized simultaneous counts at eight lookouts in the Catoctin/South Mountain range as well as a dozen along the more westerly ridges. I found that the raptor flight broke up into many minor flights along the low Maryland ridges, and then apparently became more organized along the higher Blue Ridge Mountains of Virginia. In the 1950s, I encouraged hawk migration enthusiasts to participate in coordinated studies throughout the Appalachian Mountains, and, in 1974, I was one of the founders of the Hawk Migration Association of North America, which has now been monitoring raptor migration throughout the continent for nearly 40 years.

The Albatross Problem on Midway Atoll

During World War II, the Navy took control of Midway Atoll (Midway) in the Hawaiian Leeward Chain as a base for Distant Early Warning (DEW) line flights from there to Adak in the Aleutian Islands. The nesting populations of Laysan albatrosses (*Phoebastria immutabilis*) and black-footed albatrosses (*Phoebastria nigripes*) at Midway posed a serious problem because of the large size of these birds, their huge numbers (tens or even hundreds of thousands), and the fact that they showed no fear of man or aircraft. Attempts to frighten the birds or transport their young to other islands had failed. The USGS Laboratory in Denver sent Phil DuMont and Johnson Neff to Midway in 1954 to survey the situation, set up a study site near the station hospital, and band a small portion of the population. Dale Rice and Karl Kenyon spent a year there conducting life-history studies. John Aldrich and I went to Midway in December 1956 when the adults were establishing nesting territories, studied the birds on the hospital plot, and recaptured as many previously banded birds as we could.

Chan Robbins (right) and banding crew, Midway Atoll. Photo by U.S. Fish and Wildlife Service.

Laysan albatross Wisdom, alive and nesting in 2011, Midway Atoll. Photo by U.S. Fish and Wildlife Service.

I returned with an assistant for the next nine winters, conducting counts at various positions along the runways, trying different means of intimidation (none of which worked), and establishing study sites where nests were plotted to 1-ft accuracy on a permanent grid and adults and young were banded. On one such visit, I made an historic trip up the Leeward Chain with Gene Kridler, Win Banko, Ron Walker, and David Woodside on the buoy tender *Blackhaw*, stopping en route to survey the nesting birds on Nihoa and Necker, where few naturalists had ever landed. We also camped for a night in the Alakai Swamp, where I photographed an ‘o’u (*Psittirostra psittacea*), a bird now extinct (Scott and Kepler, 2016).

I returned in 1967 to recapture and reband as many birds as possible, in hopes that they would be recaptured again before the information on their aluminum bands became illegible or the bands fell off from corrosion. Hundreds of these birds were later recaptured by other investigators, who removed my bands and replaced them with theirs. Because the Bird Banding Laboratory keeps their records by band number instead of by bird, there is no forward continuity in the records and therefore still no way to determine how long the birds live.

On a brief trip to Midway in February 2002, I recaptured a Laysan albatross that was at least 50 years old: a female, named Wisdom, which was marked with a special band for easy recognition and was still alive and nesting in 2014.
In the meantime, the Navy took two measures that we had

recommended to reduce the strike rate: they paved large strips along both sides of the runway to keep birds from nesting anywhere near flying aircraft, and they flattened the dunes from which the birds were using updrafts to fly across the runways. Midway is now a National Wildlife Refuge; the birds are protected.

Publications

Birds of Maryland and the District of Columbia

Bob Stewart and I expanded our field of investigation to include the entire State of Maryland. Frank Kirkwood's 1895 "A List of the Birds of Maryland" was long out of date and out of print. When Kirkwood died in 1945, W. Bryant Tyrrell rescued his big files of Maryland bird records and lent them to us. We contacted Maryland and Washington, D.C., bird observers, and set about gathering published and unpublished records from the first half of the 20th century. No existing State bird book contained breeding density information, but we believed it was important to document breeding densities in principal habitats throughout the State. Therefore, we prepared to do this, from marsh habitats on the Eastern Shore to apple orchards around Cumberland, to bogs, forests, and farmlands in Garrett County. Our book (Stewart and Robbins, 1958) gives breeding densities for most breeding species, many derived from my Master's thesis (Robbins, 1950) at George Washington University. It also includes distribution maps where appropriate, cites maximum counts, and shows where birds banded in Maryland have been reported.

Field Guide, Birds of North America

I am indebted to Patuxent Director Arnold Nelson for allowing me to take some time off in 1965 to work on Golden Press's "Birds of North America" with Bertel Bruun and Herbert Zim (illustrated by Arthur Singer) (Robbins and others, 1966, 1983). I had initially refused to be involved with this field guide because I saw no need for it. Roger Peterson's eastern and western bird guides were both excellent for use in the field, he and I were good friends, and I felt it was unfair to produce a competing volume. When Dr. Zim told me later that he was going to find another author and publish it anyway, I told him I would agree if Golden Press would make some concessions regarding layout. I wanted to make the Golden Press volume distinct from Peterson's: birds would be shown against a background of their typical habitat; distribution maps, text, and illustrations would be on facing pages; and sonograms would be included, supplied from my personal collection of recordings. Golden Press resisted the sonogram idea, but I insisted that was not negotiable; there simply was not enough space to provide diagnostic verbal descriptions of bird songs and calls. I also parted with tradition by using actual live measurements of hand-held birds in natural positions rather than the published lengths of stretched-out museum skins. Few people have noticed the accent marks showing how to pronounce the Latin names and the typical number of songs per minute—which can be helpful to folks who are tone deaf (for example, 2–4 per minute [/min] for Acadian flycatcher [*Empidonax virescens*], 6–11/min for eastern wood-pewee [*Contopus virens*], 20–40/min for eastern phoebe [*Sayornis phoebe*], and 50–70/min for least flycatcher [*Empidonax minimus*]).

Birds in Our Lives

Nine Patuxent staff members were among the 61 authors who contributed to the impressive "Birds in Our Lives" volume edited by Alfred Stefferud and Arnold Nelson and published by the Bureau of Sport Fisheries and Wildlife in 1966 (Stefferud and Nelson, 1966). Notable was a chapter by Patuxent chief veterinarian Carlton Herman about the interesting way that studies of birds were improving our knowledge of human health issues, a chapter by Chief of the Bird Banding Laboratory Allen Duvall on bird migration, and a chapter by former Patuxent director John Buckley on how to avoid problems with birds. Two chapters written by me included one on the Christmas Bird Count and one on exotic bird species introductions, which I coauthored with Gardiner Bump.

Special Scientific Reports—Wildlife

The chief official outlet for progress reports in wildlife studies was the USFWS Special Scientific Report series. The first in this series (Aldrich and others, 1949) was a compilation of maps of banding recoveries of waterfowl, largely by Patuxent staff members. Status reports on waterfowl, doves, woodcock, snipe and rails, albatrosses, and the Breeding Bird Survey were among the early issues.

References Cited

Aldrich, J.W., Hawkins, A.S., Addy, C.E., Jensen, G.H., Smith, A.G., Low, S.H., Stoudt, J.H., Robbins, C.S., Duvall, A.J., and Stewart, R.E., 1949, Migration of some North American waterfowl—A progress report on an analysis of banding records: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 1, 48 p. [Also available at https://archive.org/details/migrationofsomen00aldr.]

Aldrich, J.W., Lynch, John, Goodrum, Phil, Reid, V.H., Solman, V.E.F., Mendall, H.L., English, P.F., Stewart, R.E., Sheldon, W.G., Wright, Bruce, Robbins, C.S., and Burleigh, T.D., 1952, Investigations of woodcock, snipe, and rails in 1951: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 14, 58 p.

Baird, James, Robbins, C.S., Bagg, A.M., and Dennis, J.V., 1958, "Operation Recovery"—The Atlantic coastal netting project: Bird-Banding, v. 29, no. 3, p. 137–168. [Also available at http://sora.unm.edu/node/49575.]

Briggs, S.A., and Criswell, J.H., 1979, Gradual silencing of spring in Washington—Selective reduction of species of birds found in three woodland areas over the past 30 years: Atlantic Naturalist, v. 32, p. 19–26.

Clifford, C.M., Sonenshine, D.E., Atwood, E.L., Robbins, C.S., and Hughes, L.E., 1969, Tests on ticks from wild birds collected in the eastern United States for rickettsiae and viruses: American Journal of Tropical Medicine and Hygiene, v. 18, no. 6, p. 1057–1061. [Also available at http://www.ajtmh.org/content/18/6/1057.extract.]

Houston, C.S., Robbins, C.S., and Klimkiewicz, M.K., 2008, History of "computerization" of bird-banding records: North American Bird Bander, v. 33, no. 2, p. 53–65. [Also available at https://sora.unm.edu/sites/default/files/nabb_33-2_53-65v2.pdf.]

Ingraham, S.E., 1938, Instinctive music: Auk, v. 55, no. 4, p. 614–628. [Also available at https://sora.unm.edu/node/17686.]

Lowery, G.H., Jr., and Newman, R.J., 1955, Direct studies of nocturnal bird migration, *in* Wolfson, Albert, and Davis, D.E., eds., Recent studies in avian biology: Champaign, IL, University of Illinois Press, p. 238–263.

Mitchell, R.T., Blagbrough, H.P., and VanEtten, R.C., 1953, The effects of DDT upon the survival and growth of nestling songbirds: Journal Wildlife Management, v. 17, no. 1, p. 45–54. [Also available at http://dx.doi.org/10.2307/3796804.]

Robbins, C.S., 1950, Ecological distribution of the breeding Parulidae of Maryland: George Washington University, unpublished M.A. thesis, 145 p.

Robbins, C.S., 1964, A guide to the aging and sexing of wood warblers (Parulidae) in fall: Eastern Bird Banding Association News, v. 27, no. 5, p. 199–215.

Robbins, C.S., 1977, Data bank of North American breeding bird censuses: Polish Ecological Studies, v. 3, no. 4, p. 95–98.

Robbins, C.S., and Stewart, R.E., 1949, Effects of DDT on bird population of scrub forest: Journal of Wildlife Management, v. 13, no. 1, p. 11–16. [Also available at http://dx.doi.org/10.2307/3796121.]

Robbins, C.S., Bruun, Bertel, and Zim, H.S., 1966, Birds of North America—A guide to field identification: Racine, WI, Golden Press, Western Publishing Company, Inc., 360 p. [Revised 1983.]

Robbins, C.S., Springer, P.F., and Webster, C.G., 1951, Effects of five-year DDT application on breeding bird population: Journal of Wildlife Management, v. 15, no. 2, p. 213–216. [Also available at http://dx.doi.org/10.2307/3796613.]

Robbins, C.S., Bridge, D., and Feller, R., 1959, Relative abundance of adult male redstarts at an inland and a coastal locality during fall migration: Maryland Birdlife, v. 15, no. 1, p. 23–25.

Scott, J.M., and Kepler, C.B., 2016, Endangered species research in Hawaii—The early years (1965–87), *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 183–196. [Also available at https://doi.org/10.3133/cir1422.]

Short, L.L., Jr., and Robbins, C.S., 1967, An intergeneric hybrid wood warbler (*Seiurus* x *Dendroica*): Auk, v. 84, no. 4, p. 534–543. [Also available at http://dx.doi.org/10.2307/4083334.]

Stamm, D.D., Davis, D.E., and Robbins, C.S., 1960, A method of studying wild bird populations by mist-netting and banding: Bird-Banding, v. 31, no. 3, p. 115–130. [Also available at http://sora.unm.edu/node/49650.]

Stefferud, Alfred, and Nelson, A.L., eds., 1966, Birds in our lives: Washington, D.C., U.S. Fish and Wildlife Service, 561 p.

Stewart, R.E., 1952, Clapper rail studies, 1951, *in* Aldrich, J.W., Lynch, John, Goodrum, Phil, Reid, V.H., Solman, V.E.F., Mendall, H.L., English, P.F., Stewart, R.E., Sheldon, W.G., Wright, Bruce, Robbins, C.S., and Burleigh, T.D., Investigations of woodcock, snipe, and rails in 1951: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 14, p. 56–58.

Stewart, R.E., and Robbins, C.S., 1958, Birds of Maryland and the District of Columbia: Washington, D.C., U.S. Fish and Wildlife Service, North American Fauna No. 62, 401 p. [Also available at http://www.fwspubs.org/toc/nafa//62.]

Stewart, R.E., Cope, J.B., Robbins, C.S., and Brainerd, J.W., 1952, Seasonal distribution of bird populations at the Patuxent Research Refuge: American Midland Naturalist, v. 47, no. 2, p. 257–363. [Also available at http://dx.doi.org/10.2307/2422265.]

Williams, A.B., 1936, The composition and dynamics of a beech-maple climax community: Ecological Monographs, v. 6, no. 3, p. 318–408. [Also available at http://www.jstor.org/stable/1943219.]

Early Population And Contaminant Studies At Patuxent

By Russell J. Hall

I was asked to write on the topic "Early population and contaminant studies." By way of disclosure, I have to confess that I have no direct knowledge of this topic. I arrived at Patuxent Wildlife Research Center (Patuxent) in 1977, long after its major programs were well developed, so the information I provide here is secondhand. Of course, with the rare exception of research biologist Chan Robbins, who started work at Patuxent in 1946, few people still living have direct experience of those times. I was fortunate, however, to develop a close relationship with several other scientists who worked at Patuxent in the 1940s.

Much of my knowledge about Patuxent's programs in the 1930–40s was learned from random conversations with Lucille and William Stickel, who were fellow researchers during my tenure at Patuxent. In addition, I was privileged to have the opportunity to discuss the topic with Lucille a few months before her death in 2007. The remainder of what I know is derived from various written records—mostly scientific literature. While at Patuxent, I had two assignments that required me to summarize this information, and much of the discussion that follows is based on that past work (Hall, 1987, 1988). The written records are more objective, but perhaps less insightful, than the anecdotal information.

As you will read in other chapters in this volume, Patuxent was established in 1936 as a "research refuge." The term "habitat restoration" has been used (Perry, 2004), but I think there is more. Some understanding of Patuxent's purpose may be achieved by considering what was happening at that time in our Nation's history. Think of the Dust Bowl and the Great Depression, and keep in mind that many more people and much more of the landscape were involved in agriculture then than at any time since. The population was increasing, and it was expected that agricultural production would also need to increase. Agriculture already dominated much of the Nation's landscape and, by today's standards, was inefficient, wasteful, and destructive to the environment. Unless some major change occurred, America's wildlife would be subject to increasing pressure.

In response to the plethora of ongoing and impending problems, the U.S. Department of Agriculture (USDA) was gaining in size and influence, and was promoting scientific farming. Some of its units were working on the productivity side of the equation, whereas its Soil Conservation Service was engaged in applying the benefits of science to the urgent task of curtailing the wholesale wastage of natural resources that was then underway. The Bureau of Biological Survey was also deeply involved in conservation, because it was a unit of the USDA at the time of Patuxent's founding. Patuxent was not transferred to the Department of the Interior until 1940 and was developed in concert with the adjoining Beltsville Agricultural Research Center (Beltsville, MD), so it is not surprising that Patuxent's connection with agriculture was important from the beginning. Therefore, many of Patuxent's underpinnings and much of its initial focus were agriculture-related.

Dr. Durward Allen inspecting bicolor lespedeza (*Lespedeza bicolor*) at Patuxent Research Refuge, Laurel, MD, 1949. Photo by Francis M. Uhler, Patuxent Research Refuge.

One early program at Patuxent was a formal Farm Wildlife program. Two farms were operated on site, one of which was designed by the Soil Conservation Service to study enlightened farming practices that included many measures to promote wildlife. A comparable farm was designed and operated using the practices that were typical of the time. The scientists' task was to evaluate the results of the enlightened kind of farming. Many scientists believe that the program was never fully successful, mainly because of the long time needed for plants to grow and develop good wildlife habitat. One product of the studies was the booklet "The Farmer and Wildlife" by Dr. Durward Allen (Allen, 1949), based on his work at Patuxent. This document was published by the Wildlife Management Institute, Washington, D.C., and reprinted many times in response to requests by farmers.

Harvesting hay at Patuxent Research Refuge, Laurel, MD, 1952. Photo by Francis M. Uhler, Patuxent Research Refuge.

Unfortunately, however, no statistically reliable data on wildlife productivity were obtained, none of the anticipated impressive results materialized, and the program became an easy target for budget cutters. Reductions in force resulted in the termination of nearly all employees in the program. Some of the few who remained were able to grasp the emerging threats to wildlife posed by the new pesticides that were just becoming available, and their insights led to the development of what was to become the Environmental Contaminant Program.

Although the expression had not yet been coined at the time, the introduction of synthetic pesticides after the Second World War was one of the harbingers of what would later be called "the Green Revolution." These pesticides vastly increased agricultural productivity, permitting a reduction in the number of acres in cultivation, resulting in abandonment of farmlands that could later regenerate into wild lands, and ultimately contributing to wholesale population shifts from the countryside to urban areas. Only a few people appreciated the potential adverse side effects of pesticide use on wildlife at the time; fortunately, a small number of them were at Patuxent. With funding from the USDA, Patuxent became involved in a suite of studies of the new chemicals that were underway in many venues.

Think about the importance of this development for a moment, and consider why it was so fortunate that it all began at Patuxent instead of somewhere else. Patuxent had the already mentioned connection with farming practices that was fostered by the early connections with the USDA and the ill-fated Farm Wildlife program. Land was available for outdoor experiments in realistic surroundings. Facilities were, or would be in the future, available for maintaining and propagating wildlife in captivity, making large-scale, statistically valid experimental studies possible. A chemistry laboratory was present that was originally established for work on wildlife nutrition, but ultimately its emphasis could be shifted to chemical toxicology. Wildlife disease specialists who could diagnose pathologies and animal control specialists who were looking for ways to control nuisance wildlife, often with toxins, were available. The connection with wildlife population studies was also strong; methods for determining pesticide effects on populations in the field were needed, and Patuxent scientists, who were pioneering methods for estimating the abundance of bird and small mammal populations, could (and did) use their expertise to assess the results of pesticide applications. Any specialized expertise that was not available in-house could be obtained from the adjacent Beltsville Agricultural Research Center.

DDT was patented in 1940 and brought to market in 1942. It was immediately hailed as a great boon to humankind, and Paul Müller, discoverer of its insecticidal properties, was awarded the Nobel Prize in Physiology and Medicine in 1948. The first studies of DDT by Patuxent scientists were conducted in 1943, and the first papers were published in 1946, just after the end of the Second World War.

These original studies burst on the scene together in volume 10 of The Journal of Wildlife Management in 1946. They are—

- R.T. Mitchell—Effects of DDT spray on eggs and nestlings of birds;
- R.E. Stewart and others—Effects of DDT on birds at the Patuxent Research Refuge;
- N. Hotchkiss and R.H. Pough—Effects on forest birds of DDT used for gypsy moth control in Pennsylvania;
- D.R. Coburn and R. Treichler—Experiments on toxicity of DDT to wildlife; and
- L.F. Stickel—Field studies of a *Peromyscus* population in an area treated with DDT.

See the "References Cited" section below for the complete citations.

Some of the authors of these original studies were field ornithologists, but Hotchkiss was a wetland ecologist, Coburn was a disease specialist, and Stickel's ongoing research was on population ecology, emphasizing small mammals and reptiles.

Despite the apparent thoroughness of these very early studies, they failed to elucidate the true hazard to wildlife posed by DDT. For the most part, they demonstrated that DDT applications were relatively safe to wildlife when used judiciously and when application levels were conservative. Another 20 years and development of entirely new research methodologies would be required before the researchers were able to understand the effects of the chemical on bird reproduction and the mechanisms responsible for them. Studies of DDT continued through the 1950s, as did research on other synthetic pesticides, some with much more direct lethal effects.

Until passage in 1958 of the Magnuson-Metcalf Bill (Magnuson-Metcalf), which required testing of pesticides, the USDA funded most studies of pesticides at Patuxent. This outside funding was instrumental in keeping other research at

Patuxent afloat during lean times. Magnuson-Metcalf required acute and chronic studies of 200 pesticides on fish and wildlife species. Lists of publications from this period reveal that most Patuxent scientists were involved in one or more pesticide studies in addition to their permanent assignments. Passage of Magnuson-Metcalf permitted the recruitment of permanent staff for the research, and of course funding increased dramatically after the publication of "Silent Spring" by Rachel Carson (1962).

The Federal Environmental Pesticides Control Act (FEPCA) of 1972 amended the Federal Insecticide, Fungicide, and Rodenticide Act of 1947 to require manufacturers of new pesticides to perform a variety of tests to prove that the pesticide did not have "unreasonable adverse effects" on human health or the environment. Wildlife toxicity studies at Patuxent played a critical role in helping to enact FEPCA. In turn, once enacted, the statute helped provide further initiative and support for the development of additional avian toxicity tests at Patuxent.

As I noted in my book "Patuxent, Policy, and the Public Interest" (Hall, 2008), wildlife toxicology became a new career for me and for many others. It is now a recognized scientific field practiced by legions of investigators in many parts of the world. To the lists of "firsts" marking the history of Patuxent cited in this volume should be added that Patuxent was the birthplace of the wildlife toxicology discipline in the United States.

References Cited

Allen, D.A., 1949, The farmer and wildlife: Washington, D.C., Wildlife Management Institute, 84 p. [Also available at https://babel.hathitrust.org/cgi/pt?id=mdp.39015006126976.]

Carson, R.L., 1962, Silent spring: Boston, MA, Houghton Mifflin, 368 p.

Coburn, D.R., and Treichler, Ray, 1946, Experiments on toxicity of DDT to wildlife: Journal of Wildlife Management, v. 10, no. 3, p. 208–216. [Also available at http://dx.doi.org/10.2307/3795834.]

Hall, R.J., 1987, Impact of pesticides on bird populations, *in* Marco, G.J., Hollingworth, R.M., and Durham, W., eds., Silent spring revisited: Washington, D.C., The American Chemical Society, chap. 6, p. 85–111.

Hall, R.J., 1988, An annotated bibliography of field studies conducted on the Patuxent Wildlife Research Center—1940–1987: U.S. Fish and Wildlife Service Biological Report, v. 88, no. 2, 16 p. [Also available at https://babel.hathitrust.org/cgi/pt?id=uiug.30112106918979.]

Hall, R.J., 2008, Patuxent, policy, and the public interest—Reflections on a career in government science: Gainesville, FL, Lighthall Books, 253 p.

Hotchkiss, Neil, and Pough, R.H., 1946, Effects on forest birds of DDT used for gypsy moth control in Pennsylvania: Journal of Wildlife Management, v. 10, no. 3, p. 202–207. [Also available at http://dx.doi.org/10.2307/3795833.]

Mitchell, R.T., 1946, Effects of DDT spray on eggs and nestlings of birds: Journal of Wildlife Management, v. 10, no. 3, p. 192–194. [Also available at http://www.jstor.org/stable/3795831.]

Perry, M.C., 2004, The evolution of Patuxent as a research refuge and a wildlife research center: Laurel, MD, U.S. Geological Survey Patuxent Wildlife Research Center, 20 p., accessed October 3, 2011, at http://www.pwrc.usgs.gov/history/cronhist/patuxenthistory_perry.pdf.

Stewart, R.E., Cope, J.B., Robbins, C.S., and Brainerd, J.W., 1946, Effects of DDT on birds at the Patuxent Research Refuge: Journal of Wildlife Management, v. 10, no. 3, p. 195–201. [Also available at http://dx.doi.org/10.2307/3795832.]

Stickel, L.F., 1946, Field studies of a Peromyscus population in an area treated with DDT: Journal of Wildlife Management, v. 10, no. 3, p. 216–218. [Also available at http://dx.doi.org/10.2307/3795835.]

Dusky seaside sparrow tagged at Merritt Island, National Wildlife Refuge, FL, 1970.
Photo by Paul Sykes, U.S. Fish and Wildlife Service.

Migratory Bird Program at the U.S. Geological Survey Patuxent Wildlife Research Center/U.S. Fish and Wildlife Service Patuxent Research Refuge: Transformations in Management and Research

By R. Michael Erwin and Robert J. Blohm

Introduction

The Patuxent Wildlife Research Center (Patuxent), first known as the Patuxent Research Refuge, has a long and rich history of participation in the Department of Interior's (DOI) cooperative efforts to protect and conserve migratory birds in North America. This chapter describes many of the events and the people involved that constitute this important timeline for international conservation of a shared wildlife resource.

The Patuxent Research Refuge, renowned worldwide, is part of the National Wildlife Refuge System of the U.S. Fish and Wildlife Service (USFWS) that has, at different times and under a variety of organizational iterations, provided the physical location of Patuxent, the Migratory Bird Population Station (MBPS), the Migratory Bird and Habitat Research Laboratory (MBHRL), and the Laurel Branch of the Office of Migratory Bird Management (MBMO, now Division of Migratory Bird Management [DMBM]). This chapter also emphasizes the interrelations between the management objectives of the USFWS and the research program at Patuxent. Following incorporation of the research program into the National Biological Survey (NBS) and subsequently into the U.S. Geological Survey (USGS), the Migratory Bird program took on new identities, while the management functions continued to evolve within the USFWS despite these changes. Nevertheless, the USFWS and other agencies such as the National Park Service (NPS) were longstanding "clients" of the research community within DOI, and many of the former linkages between management and research were maintained.

Origins of the Migratory Bird Program

The Federal Migratory Bird Treaty Act of 1918, following earlier bird protection laws such as the Lacey Act (1900) and the Migratory Bird Act (1913), was one of the earliest and arguably one of the most important environmental laws enacted in the United States. These laws followed early efforts of protection initiated by the National Audubon Society and other organizations that recognized the devastating effect of unregulated sport and plume hunting on many species of migratory birds. As a result, more than 800 species of birds now receive protection under the act, which remains a landmark of wildlife conservation legislation, protecting our continent's migratory bird resource.

Most of the management and research on birds that occurred in the United States after the Federal Migratory Bird Treaty Act was passed, however, was directed at the agricultural impacts of birds. In fact, at the time of enactment, Federal responsibilities for migratory birds were assigned to the U.S. Department of Agriculture (USDA), Bureau of Biological Survey. Depredations on crops by blackbirds, starlings (*Sturnus vulgaris)*, sparrows, crows (*Corvus brachyrhychos*), and other species dictated much of the focus of bird research in the USDA. Ironically, rather than concentrating on conservation, the early decades were devoted mainly to controlling bird populations! During the 1930s, the Dust Bowl drought period in the interior of the country, combined with excessive hunting, severely depleted waterfowl populations, forcing some changes in Federal responsibilities. In 1940, bird research, along with the Bureau of Biological Survey, was transferred from the USDA to the DOI, under the USFWS. A major division within the new agency was the Federal Wildlife Refuge System. Several Federal refuges had already been designated (beginning with Pelican Island in Florida, designated by President Theodore Roosevelt in 1903), focusing primarily on providing quality habitat along waterfowl migration routes and at wintering areas. The Patuxent Research Refuge (the original name of Patuxent as established in 1936) was unique in being the only refuge created with the term "research" in its enabling legislation. As part of its research mission, the Federal banding program, begun in 1920 in Washington, D.C., was transferred to the Patuxent Research Refuge in 1942, where it evolved into the Bird Banding Laboratory. For more information about the early history of Patuxent, visit the Web site http://www.pwrc.usgs.gov/75th/pwrc_timeline_20110830/ and other chapters in this report.

The Early Years at Patuxent: 1936–70

Art Hawkins nest searching, Minnedosa, Manitoba, Canada, 1978. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Much of the work conducted at Patuxent from the 1930s through the 1960s was centered on basic waterfowl biology and a variety of agricultural questions. Experimental work on various seeds of aquatic plants collected across North America was started by research biologist Francis Uhler on the Patuxent impoundments. His primary motivation was to determine which species were best propagated in impounded fresh and brackish water to enhance overwintering waterfowl populations. Whereas today's ecologists consider invasive species to be a recent phenomenon in the United States, Patuxent biologists were working on the problem in the early 1950s; invasive plants and their effects on habitat conditions became focal areas of research on freshwater wetlands and in Chesapeake Bay. Water chestnut (*Trapa natans)* (Uhler, 1954) and Eurasian watermilfoil (*Myriophyllum spicatum)* (Steenis and Stotts, 1965) were two of the important invaders that prompted efforts to develop effective control measures. Much of this early natural history work at the refuge was based on individual knowledge of aquatic plant life histories, and many experiments were conducted both in greenhouses and in impoundments, albeit not in a rigorous hypothesis-testing framework. Mr. Uhler, John Steenis, and Neil Hotchkiss were some of the early Patuxent biologists who brought years of field experience to the refuge programs.

Studies of the population dynamics of waterfowl began very early at Patuxent under the auspices of the USFWS, Division of Wildlife Research, with coordinated banding programs begun in earnest in the 1950s (Hawkins and others, 1984). As mentioned earlier, national concerns for waterfowl population declines were voiced following the Dust Bowl-era droughts of the 1930s in much of the continent's interior, and later following periods of little precipitation and reduced duck numbers in the late 1940s. Banding crews were assigned to Montana, the Dakotas, and three western Canadian provinces to band flightless mallards (*Anas platyrhynchos*), as well as other ducks captured coincidentally with mallards, while adults were molting. The emphasis at this time was to determine the distribution of the mallard harvest. Other early efforts included diving duck banding in Alaska and black duck *(Anas rubripes)* banding in the Maritimes of Canada.

Biologists at Patuxent also figured prominently in early cooperative efforts to establish better ways of monitoring the status of waterfowl. Following World War II, the lack of breeding ground information on declining waterfowl populations prompted biologists and administrators in Canada and the U.S. to explore ways of developing improved methods of counting these birds and evaluating their breeding habitats across large areas of the continent in the spring. Fortunately, after the war, small aircraft were available as surplus and soon became part of the fleet used in experimental survey work of wildlife populations, namely waterfowl. Work in the air and on the ground revealed that birds could be counted by species from low-flying aircraft, and soon a statistically reliable method for determining breeding population size and distribution of waterfowl and assessing habitat conditions was in place. This annual survey, first operational in 1955, was then expanded beyond its origins in the prairie-parkland region of western Canada and the north-central U.S. to northern "bush" areas, including parts of Alaska. In the early 1960s, a second annual (July) survey was established to obtain a measure of waterfowl productivity by counting broods.

This cooperative effort to count waterfowl each year on the breeding grounds is widely recognized as one of the most reliable wildlife surveys in the world. Moreover, it remains a primary source of information used in the annual development of hunting regulations in Canada and the U.S. Biologists from Patuxent, who played key roles in this survey achievement, included Walter Crissey (see Crissey's autobiography [Crissey, 2006]), E.B. (Jake) Chamberlain, Fred Glover (see Glover, 2010), Chuck Evans, and John (Johnny) Lynch. During this period, many biologists, including flyway biologists (pilots), were associated with migratory game-bird management investigations and assigned to management offices within the USFWS (for example, Branch of Game Management, later Branch/Division of Management and Enforcement).

Because of their field responsibilities, biologists were typically often stationed around the country, including at Patuxent (Chamberlain, Glover, and Evans). Crissey, a biologist for migratory game birds in the Section of Waterfowl Management Investigations, Division of Wildlife Research, and stationed at Patuxent, was also a pilot (and later became the first director of MBPS; see below). Lynch, who was stationed in coastal Louisiana for virtually his entire career, operated a field office for Patuxent and was actively involved with surveys of snow geese (*Anser caerulescens*) and other Gulf Coast waterfowl. Chamberlain, Glover, and Evans were instrumental in evaluating the feasibility (later deemed impractical until renewed efforts in the 1980s) of establishing systematic waterfowl surveys in eastern Canada to complement efforts in the West. Over the years, Dr. Glover also participated extensively in the Canadian waterfowl banding program, as well as winter surveys in Mexico and Central and South America. Dr. Joe Linduska, editor of "Waterfowl Tomorrow" (Linduska, 1964), which chronicled at the time more than three decades of work on waterfowl in North America, including the aforementioned survey and banding efforts, was also a colleague of Crissey, Glover, and others at Patuxent in the early 1950s; he later became Chief of the Branch of Game Management in the USFWS.

Crissey also worked with Patuxent biologist Earl Atwood in the early 1950s to design and implement a national mail survey that would provide annual estimates of the number of waterfowl hunters and their harvest of ducks and geese. This approach far surpassed earlier efforts to estimate waterfowl harvest that relied on hunter bag checks, which were of little meaningful use in managing the annual kill. A few years later, Dr. Aelred Geis and Mr. Samuel Carney, both stationed at Patuxent, developed the Waterfowl Parts Collection Survey that is still conducted annually to estimate the species, sex, and age composition of the duck and goose harvest in the U.S. Among others working in the harvest surveys group at the time were Glen Smart, Ed Rosasco, and Woody Martin.

More locally, with the proximity of Chesapeake Bay to Patuxent, a good deal of waterfowl research took place in the bay, with interest in both native tundra swans (*Cygnus columbianus*) (formerly whistling swans) and non-native mute swans (*Cygnus olor),* as well as the large wintering populations of canvasbacks (*Aythya valisineria)*. These nearby wildlife resources fostered a long line of research and management work by staff centered at Patuxent that continues in various forms today.

It soon became apparent that with the successful development and implementation of several large-scale data-gathering efforts for migratory birds, and with other monitoring efforts

Leaders in Migratory Birds at Patuxent Wildlife Research Center meeting, Laurel, MD, 1969. (Left to right: 1st row, Frank Bellrose, Ian Nisbet, Ira Gabrielson, Walter Crissey, Roland Clement; 2nd row, Oliver Austin, William Drury, Robert Carrick, Eugene Dustman; 3rd row, Howard Wight, John Aldrich, Charles Henny, Kenneth Williamson, Hugh Boyd; 4th row, Lars von Haartman, Laurence Jahn, Joseph Hickey, Harvey Nelson; 5th row, Lee Eberhardt, Aelred Geis, John Gottschalk, Alexander Dzubin.) (From U.S. Fish and Wildlife Service, 1972) under consideration, the ever-growing base of information that resulted was quickly outstripping annual efforts for analysis and interpretation. Consequently, in 1961, the USFWS reorganized within the Division of Research by creating the Migratory Bird Populations Station located at Patuxent. This new but separate office was given specific responsibilities that combined both research and management functions, whereas other ongoing research activities, such as environmental contaminants, animal damage control, and wetland ecology, remained with the research facility. Special emphasis was given to the analysis and interpretation of the aforementioned large stores of information on migratory birds that were becoming available each year, in addition to other biological investigations that were assigned to the station. The internationally recognized Bird Banding Laboratory (BBL) became part of this new organization as well, and many band-recovery data, critical in the development of annual hunting regulations, added to the workload.

Walt Crissey was appointed the first director of MBPS. Other migratory bird biologists in this office included Al Geis, John P. Rogers (assistant director, following Al Geis); Chan Robbins (Non-Game Birds); Howard Wight, Bill Kiel, Jim Teer, Fant Martin, Roy Tomlinson, Jim Ruos, Bill Goudy, and Milt Reeves (Migratory Shore and Upland Game Birds); Al Duvall and Earl Baysinger (Bird Banding Laboratory); and Robert I. Smith, Kahler Martinson, Chuck Kaczynski (Kimball), Cal Lensick, Chuck Henny, Dave Anderson, Ken Burnham, and Dick Pospahala (Waterfowl).

Whereas ducks, geese, and swans were the primary focus at the outset, other migratory game-bird species, including woodcock (*Scolopax minor*), mourning doves (*Zenaida macroura*), white-winged doves (*Zenaida asiatica*), and rails, soon received much-needed attention from staff at the station. Work focused on many aspects of the annual cycle of these webless game-bird species, with particular emphasis on population status, productivity, habitat requirements, and mortality factors, including hunting (see Sanderson, 1977). Important advances were soon forthcoming. Ongoing analyses of band-recovery information helped inform the creation of two management units for woodcock in the eastern and central U.S. Biologists, including Fant Martin, Bill Goudy, and later Bill Krohn, Tom Dwyer, and others, helped establish and refine the woodcock singing ground survey, contributed to the development of valid sex and age identification criteria for harvested woodcock (using their wings [F. Martin]), and improved understanding of woodcock biology and management. Mourning dove work also benefited from staff work at Patuxent. For example, the three management units that guide the activities of dove managers today are based on an analysis of mourning dove band recoveries by Bill Kiel in the late 1950s, and Patuxent and MBPS staff helped improve the long-running call-count survey, using a stratified random sampling approach for the selection of survey routes around the country, during 1957–66. An outgrowth of Roy Tomlinson's work while at the station in the mid-1960s was the development of a comprehensive, long-range research and management program for mourning doves in the U.S. (R.E. Tomlinson, 1966, unpub. report available at the U.S. Fish and Wildlife Service, Division of Migratory Bird Management).

Parallel to the migratory game-bird work, the Animal Damage Control unit was formed at Patuxent, following the transfer of the "economic pests" programs from the USDA to DOI in 1940. The early emphasis at Patuxent was on research to evaluate how hedgerow and field border management for wildlife might minimize effects on agricultural production. One of the more productive researchers, Brooke Meanley, conducted many studies of red-winged blackbirds (*Agelaius phoeniceus*) in grain-belt areas, where the emphasis was on finding control solutions at the huge wintering roosts. His interests included rails and other marsh species in addition to blackbirds (Meanley and Webb, 1963; Meanley, 1975).

A major change in wildlife and avian science occurred after the 1962 publication of Rachel Carson's "Silent Spring" (Carson, 1962). This award-winning book has been widely recognized by environmental scientists across North America as the most influential book on the environment published in the 20th century. It spurred national concerns for both wildlife and human health. As a result, a major new research thrust was undertaken at Patuxent with the formation of a Contaminants Research program—first under Dr. Eugene Dustman, followed by Dr. Lucille Stickel—that was separate from the Migratory Bird program. This new focus provided a major impetus to the "nongame-bird" research field that had been quietly progressing under Robert Stewart and Chandler Robbins since the late 1940s. In spite of very limited funding, these two biologists produced a much-cited book on bird distribution throughout the Washington, D.C., and Chesapeake Bay area (Stewart and Robbins, 1958).

Robbins, concerned with songbird declines reported by many citizens, teamed up with Canadian Wildlife Service

Brooke Meanley banding blackbirds at night in Arkansas, 1951. Photo by Garner Allen, U.S. Fish and Wildlife Service volunteer.

Bob Stewart raking submerged aquatic vegetation in the Susquehanna Flats, Chesapeake Bay, 1950s. Photo by Paul F. Springer, U.S. Fish and Wildlife Service.

biologist Anthony Erskine to create the North American Breeding Bird Survey (BBS), using volunteers across the U.S. and southern Canada. The first full year of the BBS was 1965, when Robbins reported that about 50,000 birds had been counted (Robbins, 1965)—a truly impressive beginning of what would later become the longest running systematic terrestrial wildlife survey in North America. Today (2016), the BBS remains the monitoring standard for assessing land-bird population trends and helps inform and guide decision making within the avian research and management communities (see the Web page developed by Dr. John R. Sauer and others at the Patuxent Wildlife Research Center [http://www.pwrc.usgs.gov/bbs/bbs.html] and Sauer [2016]).

Finally, in 1965, under Dr. Dustman's leadership, the Endangered Species Research program was founded and headed by Dr. Ray Erickson. Captive propagation at Patuxent soon gained national and international prominence, with efforts focused on bald eagles (*Haliaeetus leucocephalus*) and whooping cranes (*Grus americana*) as part of broader restoration efforts to enhance their numbers in the wild.

The Environmental Era: 1970s

With the advent of Earth Day in 1970 and the support generated during the Nixon Administration for several environmental initiatives, including most prominently the passage of the National Environmental Policy Act (1972) and the Endangered Species Act (1973), funding levels in the DOI increased dramatically. The awakening of the public with the publication of "Silent Spring" (Carson, 1962) and improved media coverage of environmental incidents converged to encourage greater Federal attention to scientific research. Patuxent benefited greatly from this momentum, hiring many new scientists in the areas of environmental contaminants, endangered species, and migratory birds. These areas later became separate programs within the USFWS.

In 1972, the USFWS underwent a major reorganization with respect to migratory birds. This move was prompted first by migratory bird management responsibilities within the USFWS that were expanding quickly and needed to be addressed. Secondly, personnel involved in many management-related field activities (for example, surveys and banding) often came from many different offices spread throughout the organization, such as the Division of Research/MBPS and Division of Management and Enforcement, among others, that complicated staffing assignments. Finally, field studies on key migratory bird research topics and ongoing efforts to analyze the wealth of banding and population data, previously assigned to MBPS, needed to be maintained, at a minimum, and expanded if possible. As a result, two new offices were formed with personnel primarily from the aforementioned divisions. The Office of Migratory Bird Management (MBMO) was created to function solely on the management side of migratory bird work, whereas the other new office, the Migratory Bird and Habitat Research Lab (MBHRL), retained migratory bird research as its primary responsibility.

In effect, the dissolution of MBPS completed the separation of research and management activities related to migratory birds within the USFWS. (Later, each regional office in the USFWS began to enhance in-house capacity for migratory bird management with the addition of a Migratory Bird Coordinator and support staff to their organizational structure.) Dr. John P. Rogers was selected as the first chief of MBMO, with George Brakhage as his assistant chief; Dr. Robert I. Smith became the first director of MBHRL. Bob Smith was soon transferred to MBMO headquarters in Washington, D.C., to begin work on the lead poisoning issue in waterfowl, at which time Dr. Fant Martin replaced him as director.

Most staff members in the new management office were located at Patuxent in the Branch of Surveys, although the chief's office was headquartered in Washington, D.C., and many flyway biologists (pilots) in the Branch were assigned to field stations around the country. Mort Smith became chief of the Branch of Surveys, with Dick Pospahala as his assistant chief. Housed within this group were the Bird Banding Lab (George Jonkel, Chief); Waterfowl Population Surveys (Duane Norman, Chief, but located in Portland, OR); Harvest Surveys (Sam Carney, Chief); computer support and Electronic Data Processing (Bill Bauer, Chief); and staff specialist support (doves, woodcock, waterfowl), along with other administrative and support personnel. Similarly, most MBHRL personnel were also located at Patuxent, although some staff members were assigned to field stations around the country. Scientists involved in disciplines, such as environmental contaminants research and endangered species propagation, remained assigned to Patuxent. The office of the Atlantic Flyway Representative, located at Patuxent, was now attached to MBMO. Ed Addy had occupied this important position, first as a flyway biologist and then as the flyway representative, since the late 1940s and served as the liaison between the USFWS and the Atlantic Flyway Council until he retired in 1972; he was replaced by Warren Blandin. Both MBMO and MBHRL operated independently of Patuxent's director, although all offices shared some administrative and maintenance support and contributed to overhead costs associated with the amount of space occupied.

In spite of the organizational separation, strong connections were sustained between the MBMO and the researchers at Patuxent. Work in the late 1960s and early 1970s was devoted primarily to analyzing bird-band recoveries. This effort was led by Drs. Charles Henny and David Anderson, who established a strong statistical basis for population assessment using banding data. Beginning in 1969, an in-depth study of the mallard was begun by biologists in both offices, focusing on data that had been gathered from 20 years of field investigations in North America. Results of this work became known as the "Mallard Report Series," an eight-volume set of reports that ultimately improved understanding of mallard numbers and their relation to habitat availability and hunting mortality. This series, authored by many MBHRL/MBMO biologists, is one of the most comprehensive studies of a single waterfowl species available today.

Dr. Anderson, who left Patuxent in the mid-1970s for a USFWS Cooperative Research Unit position in Utah (then later moved to the Colorado Unit), set the bar high for quantitative wildlife population ecology research (see Burnham and Anderson, 2002). Some of his major career accomplishments that had their origins at Patuxent were in the areas of (1) distance sampling for density estimation, using line-transect methodology; (2) early computer models to facilitate band-recovery analyses; (3) early applications of capture-recapture models, using Cormack-Jolly-Seber models (see reviews by Nichols, 1992; Williams and others, 2002) that incorporated information-theoretic approaches and model comparisons as an alternative to traditional hypothesis testing; and (4) concepts borrowed from economics and engineering, particularly applications of decision theory and dynamic optimization, to solve complex natural-resource problems. Anderson has been recognized both nationally and internationally as one of the most influential researchers in the area of wildlife science and biometrics in the past 50 years.

Following the departure of Dave Anderson, Dr. Jim Nichols was hired in 1976. Although the "shoes" of Dr. Anderson would prove difficult to fill, Jim Nichols continued the outstanding quantitative modeling work that has come to define modern wildlife ecology and management. Also in the 1970s (and later in the 1980s), additional staff members were hired in MBHRL and at Patuxent who would continue to promote strong linkages between management needs for game species and population ecology. These new biologists included biometricians and computer programmers Paul Geissler, Jim Hines, John R. Sauer (transferred from MBMO), B.K. ("Ken") Williams, and Michael Conroy. A strong contingent of waterfowl field researchers was added as well, including Matthew Perry, Jerry Longcore, Michael Haramis, Ronald Kirby, Kenneth Reinecke, and David Krementz. Investigations such as the major collaboration between MBHRL scientist Matt Perry and research scientists at the Northern Prairie Wildlife Research Center in Jamestown, ND, David Trauger and Jerry Serie, focused on the canvasback (*Aythya valisineria*) and attempted to clarify key linkages among the breeding grounds in southern Canada, stopover areas along the Mississippi River, and the wintering grounds of Chesapeake Bay. Other game-bird work soon followed after the addition of new hires to MBHRL, including woodcock investigations in Maine (Bill Krohn and Tom Dwyer) and mourning dove research studies in South Carolina and Georgia (George Haas). Dick Coon was added to MBHRL staff and provided oversight to the Accelerated Research Program (ARP) in the latter half of the decade. Dr. Franklin Percival was selected as the first supervisor of the Game Bird Section.

At the same time that the Game Bird Section was gaining strength, the Non-Game Section in MBHRL was also adding research personnel, especially after the selection of Stanley

Mike Conroy conducting survey of black ducks in New Jersey, 1981. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Anderson as the section chief. Soon, Chandler Robbins would no longer be the "lone voice in the wilderness" regarding non-game issues and needs. Deanna Dawson (songbirds) joined the group, followed by Mark Fuller (raptors), Marshall Howe (shorebirds), Michael Erwin (colonial waterbirds), and Barry Noon (forest birds). Although game birds continued to be a major focus of the USFWS, administrators now recognized that major gaps existed in our knowledge of many groups of birds that were "off the radar screen" of management. Moreover, many species in fact seemed to be showing signs of severe population declines in some areas of the continent, and the aforementioned positions and others were filled to help respond to their needs. Later, during the next decade, tension grew within the agency over the traditional emphasis on game-bird studies as opposed to the relatively "upstart" non-game program. Ultimately, the passage of the Fish and Wildlife Conservation Act of 1980 and the 1988 amendment helped broaden the focus on other migratory birds and provided an important impetus for expanding and supporting the non-game program. To mitigate some of the divisiveness at Patuxent, a reorganization occurred that created groups without the labels "game" and "non-game."

The 1970s also were busy years in MBMO, on the management side at Patuxent, and the Branch of Surveys in particular began to complete its staffing and undertake a number of key initiatives in addition to routine activities. New flyway biologists (pilots) were hired and stationed at Patuxent to begin training for pilot-in-command positions. During the 1970s, these new members included Mike Cox, Jim Goldsberry, Bruce Conant, Bill Larned, and Al Novara. Staff biologist positions were also filled—Ron Reynolds (Bird Banding Lab), John Tautin (woodcock, following Joe Artmann), Dave Dolton (mourning doves), and Bob Blohm (waterfowl)—and key support personnel, including Judy Bladen, Phil Koscheka, and Fred Fiehrer, among others, were added.

One of the important assignments for the management office at Patuxent was the first comprehensive review of the spring waterfowl breeding ground survey that had been in place operationally since 1955. Dr. Dave Bowden of Colorado State University was contracted to review the statistical underpinnings of the survey and provide guidance to the office on such issues as representativeness of the sampling units (transect segments), stratification boundaries, and variance estimation, among other aspects (D.C. Bowden, 1973, unpub. report available at the U.S. Fish and Wildlife Service, Division of Migratory Bird Management). Much of the decade was spent implementing many of the recommendations of this review. Additionally, Branch of Surveys staff members, along with assistance from MBHRL biologists, helped prepare the "FES 75," the "Final Environmental Statement for the Issuance of Annual Regulations Permitting the Sport Hunting of Migratory Birds" (U.S. Department of the Interior, 1975). This seminal document firmly established the biological, legal, and administrative foundation for the annual development of hunting regulations for migratory game birds.

Jim Goldsberry and Al Novara, U.S. Fish and Wildlife Service, with aerial survey plane, Chesapeake Bay waterfowl survey, fall 1979. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

The 1980s Computer Revolution: A PC in Every Office

Although MBHRL was discontinued as a research office in 1981, its staff and function continued under Patuxent's organizational umbrella. Overall, despite this change, research personnel were nearly at full strength, and a great deal of energy and activity had developed on many fronts. Some of the key projects that involved close collaboration between MBMO staff and Patuxent's research personnel are listed in table 1. The management needs of the USFWS provided the primary focus for most of the researchers, although some research addressed the needs of other interest groups, including the NPS, U.S. Forest Service, State agencies, and other organizations. The geographic scope was by no means limited to the U.S. and Canada, however. Because migratory bird issues do not recognize international boundaries, research activities expanded to a global reach. Research staff conducted cooperative research and conservation in Mexico, Belize, Jamaica, Dominican Republic, Trinidad, Suriname, Russia, Greenland, and France, among others.

In the early 1980s, a monumental change was evident in the BBL, where the staff was transitioning from manually processing banding and recovery information to using desktop computers. The benefits of the transition, initiated by Dick Pospahala with data-processing support from Phil Koscheka and Fred Fiehrer, in terms of time, accuracy, and responsiveness to the public were soon apparent. In the mid-1980s, another major change occurred in the manner in which the government operated. Personal computers (PCs) quickly became available for every management, research, and administrative office, greatly facilitating the processing of information and accelerating the pace of data analysis and global

Table 1. Examples of joint projects between migratory bird management and research personnel at the Patuxent Wildlife Research Center from the 1960s through the 1990s.

Title of project	Period of study	Major issue or question
Annual hunting regulations	1960s and ongoing	Improve annual estimates of waterfowl breeding populations and levels of productivity
Shooting hours study	1979–80	Determine effects on waterfowl populations of potential changes in shooting times for hunting
Stabilized regulations	1980–85	Provide accurate assessments of vital rates of mallards during breeding and nonbreeding periods while hunting regulations are stabilized; continue development of mallard model
September dove hunting	Late 1970s to early 1980s	Determine effects of previous September season openings on mourning dove populations
Reward band study	1960s–90s	Update previous estimates of reporting rates of bands recovered by waterfowl hunters, with initial focus on mallards
Woodcock Singing Ground Survey	1970s–80s	Improve survey route selection and detection of breeding birds in the Northeast and Midwest
Mourning dove surveys	1980s	Same issues as woodcock
May waterfowl surveys	1970s–90s	Improve stratification needed for aerial surveys, especially in Canadian provinces; review design and other statistical aspects
Mid-Winter Waterfowl Inventory	1985–90	Review key design and operational aspects of mid-winter inventory; structure and collate aerial survey data to make flyway population estimation feasible, with focus on Atlantic Flyway
Colonial waterbird surveys	1979–80s	Improve protocols for estimating breeding populations along Atlantic Coast
Raptor surveys	1978–90s	Develop methods for estimating raptor breeding population trends in the United States.
Shorebird surveys	1978–90s	Improve protocols for the International Shorebird Survey, especially the spatial sampling frame
North American Waterfowl Management Plan	Mid-1980s—ongoing (original plan and updates)	Integrate population and habitat information, along with research questions, to achieve sustainable waterfowl populations across North America
Adaptive Harvest Management (AHM)	1990s	Incorporate Adaptive Resource Management (ARM) principles and approaches to the annual development of hunting regulations, focusing on the mallard

information dissemination. Over the next 5 years, scientists became trained in a wide variety of new software for statistical analysis in addition to manuscript development. Gone were the days of decks of computer cards, carbon copies, and multilith offset printing, among other vestiges of the precomputer era. The new "e-mail" was catching on in the 1980s as well, vastly reducing the time scientists needed to spend on letter preparation and telephone conversations.

The advent of PCs greatly reduced the amount of time required for statistical analysis and modeling, as "down time" spent waiting for mainframe computer runs became a thing of the past. Major statistical programs, such as SAS, SPSS, and others, were adapted to perform on PCs, greatly enhancing the individual scientist's capacities. One example of an area in which sophisticated analysis and modeling were facilitated by PC use was the development of the "mallard model," a comprehensive effort initiated in the early 1970s by Dave Anderson and elaborated upon by Jim Nichols and Jim Hines at Patuxent, among others, to better understand the demography of the North American mallard population. Key MBMO scientists at Patuxent teamed with researchers at the center and its Vicksburg, MS, field station (Dr. Ken Reinecke) and the Northern Prairie Wildlife Research Center (Dr. Doug Johnson, Dr. Lew Cowardin, and others) to use PCs to greatly improve our understanding of mallard demographic parameters and consolidate numerical estimates of key vital rates.

One MBMO initiative in the 1980s stands out in terms of its purpose, scope, and involvement by research and management staff, not only at Patuxent but at many other agencies and organizations—an evaluation of the effect of stabilized hunting regulations on ducks in the U.S. and Canada. This program, known as the "Stabilized Regulations Study," was a massive undertaking of resources and staff in both countries, beginning in Canada in 1979 and in the U.S. in 1980, and terminating in 1985. Focused on the mallard, this investigation attempted to answer a series of questions related to mallard biology and management during a period when hunting regulations (season lengths and bag limits) were held constant. The study culminated in many reports and peer-reviewed publications, which reflected well on the MBHRL and MBMO staff at Patuxent who helped design and carry out this cooperative undertaking (see McCabe, 1987).

Following the conclusion of this initiative, MBMO/Branch of Surveys staff members, along with support from MBHRL scientists, assisted in the preparation of "SEIS 88," the "Final Supplemental Environmental Impact Statement: Issuance of Annual Regulations Permitting the Sport Hunting of Migratory Birds" (U.S. Department of the Interior, 1988). This important document was a follow-up to the original environmental impact statement published in 1975. In 1984, Dave Bowden was again asked to review the May aerial survey for breeding waterfowl and the Branch of Surveys was tasked with evaluating Bowden's recommendations, culminating in a major report by Graham Smith (Smith, 1995). Finally, a collaborative effort of research and management scientists at Laurel produced an important study of reporting rates of banded waterfowl conducted by using reward bands. These studies followed an earlier investigation by Drs. Chuck Henny and Ken Burnham at Patuxent in the 1970s that had provided the most recent baseline of reporting rates of recovered bands available at the time. Information from the 1980s study and subsequent investigations ultimately helped optimize continental banding efforts of waterfowl and had a profound effect on BBL operations.

The 1980s also saw many staff and organizational changes within MBMO that affected the migratory bird management program at Patuxent. Following the untimely death of Warren Blandin in 1982, Jerry Serie left a research scientist position at the Northern Prairie Wildlife Research Center to become Atlantic Flyway Representative. Sam Droege came to the Branch of Surveys as coordinator of the BBS when it was part of the migratory bird management program, and Alan Davenport transferred from Northern Prairie as well, bringing his computer expertise to the branch. Drs. Bob Trost and John Sauer were hired to provide biometric support to the Branch of Surveys, while Brad Bortner, Dave Sharp, Sean Kelly, and Fred Johnson added migratory game-bird expertise, joining other biological and administrative staff in the newly formed Population Assessment Section, headed by Dr. Bob Blohm. New pilot-biologists included John Solberg, Fred Roetker, Jim Bredy, Carl Ferguson, and Jim Walter, all of whom spent time training at Patuxent before being assigned to respective field stations around the country. After the departure of John Rogers as chief of MBMO and the retirement of George Brakhage, key openings in the office were soon filled by Dr. Rollin Sparrowe as chief, and Dr. Ken Williams as his deputy. The latter move further exemplified the ongoing close relationship between research and management programs and personnel at Patuxent, as Williams left his biometrician position in MBHRL to assume supervisory responsibilities in MBMO. At Patuxent, Dr. Robert I. Smith became Chief of the Branch of Surveys after Mort Smith was transferred to MBMO's Washington, D.C., office. George Jonkel and Sam Carney retired at the end of the decade and were replaced by John Tautin and Dr. Paul Geissler, respectively.

The "Identity Crises": 1990s

Because of major political shifts in Washington, D.C., in the early and mid-1990s, two monumental reorganizations occurred within DOI that affected Patuxent. Then-Secretary Bruce Babbitt formed a new Interior science agency, known as the National Biological Survey (which later became the National Biological Service, or NBS), by combining all research personnel within DOI, including those from USFWS, NPS, and Bureau of Land Management, into one Bureau. Biologists at major research centers, such as Patuxent, Northern Prairie, Denver, and others, along with staff at cooperative research units located at many universities across the country, soon found their organizational allegiance drastically changed. Even the BBL and BBS at Patuxent, whose missions were management oriented, were caught up in this restructuring. This move was in response to criticism about science, policy, and regulatory authorities being located within the same agencies. Not surprisingly, because of this unexpected reorganization, Patuxent scientists and administrators suffered through a great deal of confusion and program uncertainty. Still more changes were on the horizon. In the midst of all this restructuring, political battles were still being waged in the corridors of Washington, D.C. Only 2 years after the NBS had been formed, discussions were underway to make yet another change—and this time the future of all of DOI research was at stake.

To "save" the approximately 1,800 scientists in NBS, Secretary Babbitt merged the former NBS with the U.S. Geological Survey (USGS) in 1996, to become a fourth unit, the Biological Resources Discipline (BRD), within the USGS. Therefore, the disciplines of water resources, geology, and mapping now included wildlife research biologists, biometricians, and other staff under the same organizational "umbrella." Scientists at Patuxent, as well as their peers at former USFWS research units, faced a major redirection of their scientific mission, not once but twice. In migratory birds, instead of focusing on the trust species of the USFWS and issues important to national wildlife refuges and international treaty obligations, the former USFWS scientists now were obligated to deal with all the DOI land and resource issues. Similarly, scientists who had spent their entire careers at national parks conducting NPS research were asked to expand their scope considerably under the USGS flag, in some cases at a different location, such as Patuxent. Consequently, after merging with the USGS, Patuxent's science plan suddenly looked very different within an agency whose culture had historically been defined by the physical sciences. Gone was a "migratory birds" program, as well as separately funded programs for contaminants or endangered species. Instead, more generic scientific objectives were established that, in the biological discipline, focused on ecosystem research, with little emphasis on population-level science or species conservation concerns.

Following several changes in USGS directors since 1996, administrative alignments and objectives too have changed; moreover, after more than a decade, the former USFWS and NPS biologists have acclimated to the new research model. Another shift in the paradigm has been the fostering of researcher alignments with research universities. These cooperative arrangements have long been part of the culture of the USFWS (the Cooperative Fish and Wildlife Research Unit program) and NPS (Cooperative Parks Studies Unit program), but most researchers in the USGS traditionally had been based at a small number of centers independent of university campuses (for example, Menlo Park, CA; Woods Hole, MA; and Reston, VA [USGS headquarters]). Today, the presence of biologists at universities across the country has spawned the formation of many local and regional partnerships addressing a wide variety of fish and wildlife resource issues. In addition, these strong university ties have facilitated the training of many graduate and post-graduate students by Patuxent scientists.

In spite of this functional upheaval in the traditional pursuits of wildlife ecology, conservation, and management, many important projects and advancements occurred during the 1990s and early 2000s. Many of these involved extensive interactions among Patuxent researchers, visiting scientists and post-doctoral students, and migratory bird management personnel in the USFWS and other agencies. Again, one contributing factor was the increasing use of PCs, which improved the efficiency of model development and prompted other innovative statistical approaches, making them more accessible to the wider scientific community around the world. Jim Hines, a longtime associate of Jim Nichols, became one of the country's premier computer programmers in the area of wildlife demographic modeling. His development of user-friendly software has enabled wildlife researchers worldwide to access upgraded capture-recapture models for closed and open populations, occupancy models for metapopulation analyses, and other decision-support tools. The importance of this long-term, productive collaboration between Nichols and Hines cannot be overstated.

Within the Migratory Bird program of the USFWS, the decade of the 1990s was highlighted by major changes in a longstanding survey effort centered at Patuxent and by a major paradigm shift in the decision-making process with respect to establishing annual harvest regulations. Not unexpectedly, staffing and organizational changes occurred during this decade as well.

Although problems with response rates in the harvest survey program had been recognized previously, levels reached unacceptable lows in the 1980s, prompting the waterfowl management community, particularly the USFWS, to seek alternative approaches. Initiated at the request of the International Association (now Association) of Fish and Wildlife Agencies in 1991, the new Harvest Information Program (HIP) moved away from the previous sampling frame based on duck stamp purchases to one that required licensed hunters to identify themselves as migratory bird hunters and supply name, address, and other information necessary for subsequent sampling efforts. Following a pilot stage and staggered entrance of states into the new system, the HIP survey became fully operational in 1998 and today stands as a much more reliable method for assessing hunter activity and success, not only for waterfowl but for other species of migratory game birds as well. Dr. Paul Padding, newly hired to the Harvest Surveys staff at Patuxent, provided overall guidance that contributed to the program's successful development and implementation, with critical assistance from Dr. Paul Geissler (formerly of MBHRL), Mary Moore, Bob Jessen, and Larry Hindman (Maryland Department of Natural Resources).

Against the backdrop of declining duck populations in the 1980s, ongoing high demand for more hunting opportunities, and longstanding uncertainty about the effects of hunting on migratory bird populations that continued to generate high levels of controversy, the stage was set in the early 1990s for a dramatic change in the annual regulations-setting process for waterfowl hunting. Beginning in 1992, MBMO, along with research scientists at Patuxent and with the support of all four Flyway Councils, embarked on a long but successful collaboration to bring about needed changes in harvest management. The objectives of this cooperative effort were to help improve managers' understanding of the effects of hunting regulations on harvests and population levels, to maximize cumulative harvests over the long term, while maintaining waterfowl populations at or above objective levels, and at the same time to provide a more informed and objective decision-making process for addressing harvest management issues each year. This process, an outgrowth of Adaptive Resource Management (ARM), focused from the beginning on the population dynamics and harvest potential of mallards. It became known as Adaptive Harvest Management (AHM) and was fully implemented in 1995. Although many individuals contributed to AHM's development and implementation over the years, the hub of activity was at Patuxent, where Fred Johnson (MBMO) provided the theoretical framework, along with Jim Nichols, Ken Williams, Graham Smith, Bob Trost, Bill Kendall, Jim Dubovsky, Dave Caithamer, and later Scott Boomer and Mike Runge, and many others in the research and management offices. This highly successful program continues to this day, and its value to waterfowl management can be directly attributed to the involvement from the beginning of biologists from Federal, State, and nongovernmental agencies (NGOs) and organizations.

The New Millennium: Research into New Dimensions

Once the wildlife programs were merged with other USGS research priority areas, the momentum shifted away from traditional species and community approaches to consider topics such as ecosystem dynamics, global climate change, and environmental health. Although new allegiances and partnerships were being formed within and outside the USGS community, and despite changing scientific missions, the legacy of wildlife population dynamics at Patuxent managed to continue uninterrupted. As proof, a major manuscript was completed early in the 2000s and published in book form, marking the culmination of two decades of work on population demographic analysis and effective wildlife management (Williams and others, 2002). The authors —Ken Williams, Mike Conroy, and Jim Nichols—were all collaborating Patuxent researchers in the 1980s, although Williams and Conroy later left for other positions.

Increasing concern about climate change in the Federal science agencies resulted in major funding initiatives for Patuxent and other USGS research facilities. Patuxent scientists focused on studying possible effects of coastal sea-level rise on lands under management policies of the USFWS, NPS, States, and NGOs. Don Cahoon, Glenn Guntenspergen, and Mike Erwin all initiated studies at many Atlantic coastal (and international) sites in which surface elevation tables were used to compare marsh dynamics to relative sea-level rise.

On the management side, the 2000s marked an expansion of the biological staff at Patuxent. The Branch of Population and Habitat Assessment (formerly the Population Assessment Section), with Mark Koneff as chief, added many migratory bird specialists, including nongame biologists—many with advanced quantitative skills—who collectively provided a level of expertise in population ecology and modeling matched only by Patuxent's USGS scientists. In addition to carrying out traditional responsibilities related to operational surveys and the annual regulations development process, staff members provided continued support to AHM and HIP, and embarked on new initiatives. Some of these included waterfowl population survey improvements (Emily Silverman); development of more informed, model-based harvest strategies for woodcock (Guthrie Zimmerman) and mourning doves (Mark Seamans, Todd Sanders); additional reporting rate investigations (Pam Garrettson, Andy Royle); and adaptive harvest strategies for waterfowl other than mallards (for example, northern pintails [*Anas acuta*], Mike Runge [Patuxent]; American black ducks, Mike Conroy [USGS, retired], Pat Devers; and scaup [*Aythya affinis and A. marila*], Scott Boomer).

In the 2000s, the longstanding work and collaboration on AHM at Patuxent finally began to have far-reaching ramifications in the natural-resource community. Because of the ongoing success of AHM in helping biologists manage waterfowl harvests, and because of the willingness of key individuals in research and management to share their knowledge and understanding of this new management approach, a paradigm shift in the way natural-resource issues could be resolved was taking place outside the migratory bird management arena. Today, ARM has been accepted within DOI as a policy approach for resolving natural-resource management issues on Federal lands and for helping to fulfill Federal mandates for trust species. Some of the projects involving substantial management input to the research planning process during the past decade are listed in table 2. The first eight projects listed involve a continuation of the linkages between the management personnel (formerly MBMO, renamed Division of Migratory Bird Management in 2000) and researchers at Patuxent, including the BBL. The remaining projects involve substantial input from the refuge component of the USFWS and from the NPS. Additional shared research/management projects that have emerged include management activities within other State, Federal, and international agencies, such as:

1. **Avian disease ecology**—Since 2005, with the outbreak of avian influenza in bar-headed geese (*Anser indicus*) at Qinghai Lake in western China and its potential for global spread to humans, Patuxent and other USGS facilities have been engaged in research in east Asia (Jiao, 2010). The "management" agencies now include the United Nations Food and Agriculture Organization, USFWS, USGS, USDA, and many Chinese science and

Table 2. Recent (1990s to present [2016]) projects involving collaboration of Patuxent Wildlife Research Center migratory bird researchers with management personnel on studies of mutual interest, and related scientific advances.

Title of project or study	Time period	Related scientific advances
Capture-recapture modeling	1990s and ongoing	Expansion of applications to estimate species richness; development of methods for coping with detectability differences, multistate populations, and missing data; development of user-friendly software
Occupancy modeling	1990s and ongoing	Expanded use of models to consider larger metapopulation dynamics, colonization, dispersal, range shifts, and epidemiology; software development
Status of migratory bird populations across the United States and Canada	1990s and ongoing	Accessibility of summary results from Breeding Bird Survey to increase knowledge of status and trends of many North American landbirds and some game-bird species
Adaptive management of migratory game-bird species	1990s and ongoing	First application of Adaptive Resource Management (ARM) principles to harvest regulations for mallards, American black ducks, and other species and populations of waterfowl
Additional reward band studies	1990s and ongoing	Availability of reporting rate information available for other species besides mallards; optimization of banding needs
Updated Supplemental Environment Impact Statement 88	2006–11	Updated information that supports the biological, legal, and administrative aspects of promulgating annual hunting regulations for migratory game birds
Improved harvest strategies for migratory game birds	1990s and ongoing	Improved use of available information to make more informed harvest management decisions
Priority research and management needs for migratory shore and upland game birds	2006–11	Identification of top research and management activities to address needs; enhancement of funding request justifications
Wetland mitigation studies	1990–98	Improved approaches to water management on Patuxent Research Refuge property
Coastal sea-level rise on Federal lands	1998 and ongoing	Use of surface elevation tables on refuges and National Park Service lands to evaluate refuge and other Federal lands most vulnerable to sea-level rise
Open marsh water management on Federal lands	1999–2006	First large-scale experimental approach to studying effects of hydrologic manipulations on salt-marsh environments
Integrated Waterbird Monitoring and Management	2009 and ongoing	Application of principles of ARM and Structured Decision-Making (SDM) to wetland management in the eastern United States to optimize use by a diverse water-bird community
Wind turbine impacts in eastern mountain ridges	2005 and ongoing	Experimental application of acoustic receptors at proposed turbine locations in the Appalachian region; documentation of bird and bat impacts
Seaduck movements and trophic relations	2004 and ongoing	Discovery of new routes used during migration and staging in Canada; collection of new energetic information (captive flock)

forest agencies. The research activities have expanded from using satellite telemetry to monitor selected species of waterfowl in China and Mongolia to developing risk models based on poultry farm distributions and wildlife migration movements in eastern Asia (see http://www.usgs.gov/blogs/features/usgs_science_pick/understanding-global-avian-influenza-transmission-pathways-through-ecology/). Other USGS researchers have added study sites in Africa and parts of the Middle East to the East Asian locations. Close coordination with the USFWS was facilitated by the 2008 hiring of an Avian Disease Coordinator, Dr. Samantha Gibbs, in the DMBM.

2. **Structured Decision-Making (SDM)**—The increased complexity of natural resource issues, many of which have competing demands, has led to the emergence of a new paradigm to formulate effective management planning. The popularity of SDM, an outgrowth of ARM, has increased among Federal agencies over the past several years (Martin and others, 2009). One demonstration of it has been on a multirefuge study across the Northeast and Midwest to assess impoundment management for waterbirds (Lyons and others, 2008). The approach, many of whose elements are borrowed from systems theory, has broad appeal to a wide audience of managers. Challenges in determining the timing and spatial scale of management implementation can be addressed using SDM. Also, the SDM approach can be useful in seeking optimal solutions where many management objective functions have been identified. Patuxent and DMBM scientists have offered training classes in SDM applications.

3. **Offshore energy infrastructure**—The need for exploration to discover additional energy sources, including wind generation and new oil/natural gas fields, demands that environmental impacts be evaluated. In the past 5 to 6 years, Patuxent has been engaged with the Bureau of Ocean Energy Management (formerly Minerals Management Service), the USFWS, and several State agencies and NGOs in evaluating the potential for impacts of turbine or rig installations on migratory birds. Some of the research has focused on marked individual seaducks in Nantucket Sound, MA, including the identification of their foraging and roosting locations during winter, in conjunction with a broader seaduck study in the U.S. and Canada. In addition, a large database has been developed to capture available information on seabird distributions along the entire Atlantic Coast.

4. **Island restoration**—The demands of shipping and maintenance of navigation channels along the coast require the U.S. Army Corps of Engineers and State management agencies to coordinate disposal plans for millions of cubic yards of dredged materials. One such large-scale project that has involved Patuxent since the mid-1990s is the Paul Sarbanes Ecosystem Restoration Project at Poplar Island in Talbot County, on Maryland's Eastern Shore (see http://www.nab.usace.army.mil/About/ProjectFactSheets.aspx). This "Beneficial Use" project requires that the restoration of the approximately 1,150-acre island provides equal areas of uplands (up to about 8.6 yards above North American Vertical Datum of 1988) and wetlands. The objective for the wetland area is to attract key species of nesting and migrating waterbirds, nesting diamondback terrapins (*Malaclemys terrapin*), fishes, and other species. Patuxent scientists have been major participants in habitat design for the project area and monitoring of use by waterbirds and breeding success since 2002 (Erwin and others, 2007).

Conclusions

Patuxent's program for migratory birds, like most Federal programs, has been altered dramatically over the past 80 years as bureaus reorganized, administrations forced a reexamination of priorities, funding levels fluctuated, and scientific personnel came and went. Nevertheless, the level of scientific activity has remained consistently high, with Chandler Robbins serving as the "guiding light" in his 60 years of dedicated research service. Scientists located at Patuxent and working in either wildlife research or wildlife management have taken active roles in forging new initiatives in a number of key areas over the years. Some examples are—

- Managing aquatic vegetation in impoundments to support waterfowl;
- Expanding the capabilities and efficiency of the BBL to allow sophisticated distribution and population analyses of both hunted and nonhunted species of birds;
- Developing rigorous national/international bird surveys for waterfowl, woodcock, mourning doves, and other webless migratory game-bird species to support the promulgation of annual hunting regulations;
- Improving or formulating more effective inventory and monitoring methods for songbirds, shorebirds, raptors, and colonial waterbirds, and extending the training to a number of underdeveloped countries in the Western Hemisphere;
- Initiating the BBS across the U.S. and Canada, and later making the summaries of trends of species available on the World Wide Web;
- Developing and expanding new applications of capture-recapture and occupancy modeling beyond estimating survival and abundance parameters of populations;
- Applying ARM and SDM to complex natural resource problems, including more informed management of harvests of migratory game birds;

- Drafting national plans to manage and conserve waterfowl, waterbirds, shorebirds, and raptors; and
- Studying the movements of waterfowl in East Asia and investigating mechanisms of the transmission and spread of avian influenza (H5N1) within wild populations and among wild and domesticated poultry during seasonal movements.

The inclusion of Patuxent as part of the USGS—an agency dominated by the physical sciences—has broadened its purpose, and studies of migratory birds continue in different forms. More specifically, studies of bird populations and the development of methods for effectively managing those populations are now typically cast in relation to predicted climate change, threats to conservation, effects of mineral and energy facility expansion, and considerations of human and animal health.

Within the USFWS, a separate programmatic home, apart from the Refuge program, was created for migratory birds in the early 2000s under a new assistant director (first, Tom Melius as Assistant Director for Migratory Birds and State Programs in 2000; and later, Paul Schmidt as Assistant Director for Migratory Birds in 2003). This change provided many obvious benefits and advantages in terms of priority-setting and program delivery. In recent years, however, a broadening of the program's mission has been observed in this agency as well, with more involvement of migratory bird staff, including those at Patuxent, in large-scale initiatives on the landscape.

Another challenge for both the USGS and USFWS in the future is coordination among the many Federal, NGO, State, university, and other agencies and organizations interested in both research on and management of birds and their habitats at different scales. Just a partial list reveals how large the scope of partnerships has become: regional, national, and international Joint Ventures and other bird conservation plans under the North American Waterfowl Management Plan and North American Bird Conservation Initiative (NABCI); the new USGS National Climate Change and Wildlife Center, with eight centers distributed around the county; the new Landscape Conservation Cooperatives (joint Federal and university projects, with USFWS and USGS); The Nature Conservancy's Conservation By Design program; and others, such as programs shared with Ducks Unlimited, the U.S. Forest Service, and various State programs (for example, Florida's Forever Wild). Without a scorecard, it will be very difficult to keep up with developments in all these initiatives to reduce redundancy and overlap. In these times of very limited public funding, it is essential to ensure that management and research dollars are allocated in the most effective way possible.

Finally, Patuxent's many accomplishments over the last 80 years could not have been achieved without a conscious effort on the part of research and management staff to maintain longstanding and productive working relationships. These professional bonds formed at Patuxent have ensured continual collaboration among staff, despite those many factors, both internal and external, that have continued to threaten program viability. It is a rich history and a lasting testament to these individuals that research and management programs at Patuxent have sustained their high visibility and value to the conservation and management of our natural resources for three-quarters of a century. There is no reason to believe that this relationship will not endure well into the future.

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Tom Custer weighing heron chick at a dredge island site in Lavaca Bay, Calhoun County, TX, in 1988. Photo by R. Will Roach, U.S. Fish and Wildlife Service.

References Cited

Burnham, K.P., and Anderson, D.R., 2002, Model selection and multimodel inference—A practical information-theoretic approach (2d ed.): New York, Springer-Verlag, 488 p.

Carson, R.L., 1962, Silent spring: Boston, MA, Houghton Mifflin, 368 p.

Crissey, W.F., 2006, A life like no other—The autobiography of Walter F. Crissey: Bloomington, IN, iUniverse, Inc., 468 p.

Erwin, R.M., Miller, Jason, and Reese, J.G., 2007, Poplar Island Ecosystem Restoration Project—Challenges in waterbird restoration on an island in Chesapeake Bay: Ecological Restoration, v. 25, no. 4, p. 256–262. [Also available at http://er.uwpress.org/content/25/4/256.abstract.]

Glover, F.A., 2010, Muskeg to mangrove—A flying biologist's story (2d ed.): Washington, D.C., U.S. Fish and Wildlife Service, 286 p.

Hawkins, A.S., Hanson, R.C., Nelson, H.K., and Reeves, H.M., eds., 1984, Flyways—Pioneering waterfowl management in North America: Washington, D.C., U.S. Department of the Interior, U.S. Fish and Wildlife Service, 517 p.

Jiao, Li, 2010, In China's backcountry, tracking lethal bird flu: Science (Newsfocus), v. 330, no. 6002, p. 313. [Also available at http://dx.doi.org/10.1126/science.330.6002.313.]

Linduska, J.P., ed., 1964, Waterfowl tomorrow: Washington, D.C., U.S. Department of the Interior, 770 p.

Lyons, J.E., Runge, M.C., Laskowski, H.P., and Kendall, W.L., 2008, Monitoring in the context of structured decision-making and adaptive management: Journal of Wildlife Management, v. 72, no. 8, p. 1683–1692. [Also available at http://dx.doi.org/10.2193/2008-141.]

Martin, Julien, Runge, M.C., Nichols, J.D., Lubow, B.C., and Kendall, W.L., 2009, Structured decision-making as a conceptual framework to identify thresholds for conservation and management: Ecological Applications, v. 19, no. 5, p. 1079–1090. Also available at http://www.jstor.org/stable/40347252.]

McCabe, R.E., 1987, Results of stabilized duck hunting regulations: Transactions of the North American Wildlife and Natural Resource Conference, v. 52, p. 177–326.

Meanley, Brooke, 1975, Birds and marshes of the Chesapeake Bay country: Cambridge, MD, Tidewater Publishers, 157 p.

Meanley, Brooke, and Webb, J.S., 1963, Nesting ecology and reproductive rate of the red-winged blackbird in tidal marshes of the upper Chesapeake Bay region: Chesapeake Science, v. 4, no. 2, p. 90–100. [Also available at http://dx.doi.org/10.2307/1350827.]

Nichols, J.D., 1992, Capture-recapture models—Using marked animals to study population dynamics: BioScience, v. 42, no. 2, p. 94–102. [Also available at http://dx.doi.org/10.2307/1311650.]

Robbins, C.S., 1965, Fifty thousand birds recorded on Breeding Bird Survey: Maryland Birdlife, v. 21, no. 3, p. 73–79.

Sanderson, G.C., ed., 1977, Management of migratory shore and upland game birds in North America: Washington, D.C., International Association of Fish and Wildlife Agencies, 358 p.

Sauer, J.R., 2016, Patuxent's role in the development of the Breeding Bird Survey, *in* Perry, M.C., The history of Patuxent—American's wildlife research story: U.S. Geological Survey Circular 1422, p. 53–64.

Smith, G.W., 1995, A critical review of the aerial and ground surveys of breeding waterfowl in North America: Washington, D.C., U.S. Department of the Interior, National Biological Service, Biological Science Report 5, 252 p. [Also available at http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA322667.]

Steenis, J.D., and Stotts, V.D., 1965, Tidal dispersal of herbicides to control Eurasian watermilfoil in the Chesapeake Bay: Proceedings of the Southern Weed Conference, v. 18, p. 507–511.

Stewart, R.E., and Robbins, C.S., 1958, Birds of Maryland and the District of Columbia: Washington, D.C., U.S. Fish and Wildlife Service, North American Fauna No. 62, 401 p. [Also available at http://www.fwspubs.org/toc/nafa//62.]

Uhler, F.M., 1954, Water chestnut menaces upper section of Chesapeake Bay: Maryland Sportsman, v. 12, no. 9, p. 4–5.

U.S. Department of the Interior, 1975, Issuance of annual regulations permitting the sport hunting of migratory birds: Washington, D.C., U.S. Fish and Wildlife Service, Final Environmental Impact Statement, 710 p. plus appendixes.

U.S. Department of the Interior, 1988, Issuance of annual regulations permitting the sport hunting of migratory birds: Washington, D.C., U.S. Fish and Wildlife Service, Final Supplemental Environmental Impact Statement, 340 p.

U.S. Fish and Wildlife Service, 1972, Population ecology of migratory birds: Washington, D.C., U.S. Fish and Wildlife Service, Wildlife Research Report 2, 278 p.

Williams, B.K., Nichols, J.D., and Conroy, M.J., 2002, Analysis and management of animal populations (1st ed.): San Diego, CA, Academic Press, 817 p.

Blue-winged teal, Little Compton, RI, 1966. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

The Bird Banding Laboratory: Support for and Collaboration with Research at Patuxent

By John Tautin

Located at Patuxent Research Refuge (PRR) and functionally part of the Patuxent Wildlife Research Center (Patuxent), Laurel, MD, the Bird Banding Laboratory (BBL) is the service and administrative center for bird banding in the United States. Over the years, the BBL has been associated with both the PRR and Patuxent, which collectively are commonly referred to by the public (and in this chapter) as "Patuxent." The BBL issues permits and bands; supplies banding software, instructional materials, and technical advice; coordinates the use of auxiliary markers such as neck collars and radio transmitters; serves as the repository for banding records and the clearinghouse for reports of banded birds; disseminates data to researchers and managers; and assists in the development and coordination of banding projects. The BBL is a large and complex operation with a long and rich history that predates its transfer to PRR in 1942, when it began a remarkably successful and mutually beneficial collaboration with research and management functions colocated at PRR. Prior to 1961, the BBL was known simply as the "bird banding office."

Bird Banding Begins: The Bird Banding Laboratory before Patuxent

Scientific bird banding began in 1902, when Smithsonian Institution scientist Dr. Paul Bartsch banded several black-crowned night-herons (*Nycticorax nyticorax*) along the Anacostia River in Washington, D.C. Bartsch used serially numbered bands with a Smithsonian return address on them and, in 1904, he published results from his banding study (Bartsch, 1904). In a prescient statement that began, "There are still many unsolved problems about bird life…." Bartsch suggested that bird banding would become a useful scientific tool.

Indeed, banding caught on quickly in the U.S. and Canada (Cole, 1922; Jackson, 2008). It was managed privately until 1920, when the Federal bird banding office was established in Washington, D.C. Federal involvement in bird banding was both logical and welcome. The 1916 Convention between the U.S. and Great Britain (for Canada) for the Protection of Migratory Birds had established Federal preeminence in migratory bird matters, and the subsequent 1918 Migratory Bird Treaty Act made it law. The banding community actually encouraged the entry of the Federal government into the management of bird banding. World War I was underway, private support for banding had waned, and an entity with sufficient resources and authority to manage bird banding was needed. That entity was determined to be the already well-established U.S. Bureau of Biological Survey (Bureau).

The Bureau had some experience with bird banding (Wetmore, 1915), and Bureau administrators, notably Edward Nelson, Bureau Chief, and Harry Oberholser, head of bird studies, were supportive and recognized the need for a well-organized, central banding office. Therefore, in 1920, in arguably one of the most fortuitous appointments in the history of North American ornithology, they recruited Frederick C. Lincoln to organize the bird banding office (Tautin, 2008).

Lincoln was a remarkably accomplished biologist, writer, and administrator. By the end of the 1920s, he had organized the banding office, developed numbering schemes and record-keeping procedures, established standards, recruited bird banders, and fostered international cooperation. He was also a visionary who tirelessly promoted banding as a tool in scientific research and management. His contributions were significant and included the development of the Lincoln index (Lincoln, 1930; later modified to become the Lincoln-Petersen index), which ultimately proved to be a true population estimator (Nichols and Tautin, 2008), and the flyways concept (Lincoln, 1935), which is still applied in waterfowl management today. As his career progressed, Lincoln took on additional responsibilities, but he remained the primary official of the bird banding office until 1946, overseeing its transfer from Washington, D.C., to Patuxent in 1942. Lincoln retired in 1947, leaving a remarkable legacy. Much has been written about his career and achievements (Terres, 1947; Gabrielson, 1961; Reeves, 1984; Tautin, 2005). Frederick C. Lincoln truly was the founder of the bird banding program as we know it today.

The Bird Banding Office Moves to Patuxent

World War II prompted the move of the bird banding office to PRR. During the summer of 1942, in accordance with a decentralization order by President Roosevelt, the main offices of the U.S. Fish and Wildlife Service (USFWS) were moved temporarily to Chicago. However, the bird banding and other migratory bird files, together with the staff members who worked with those files, were moved to PRR (later Patuxent), where space in Nelson Laboratory was available.

After the war, the USFWS returned to Washington, D.C., but the bird banding office stayed at Patuxent, where it remains today, known as the BBL. The move to Patuxent was most fortunate for bird banding, because Patuxent would eventually become a world-class center for migratory bird research and management. The colocation of the bird banding office with scientists, who developed methods for analyzing banding data, and with management-oriented biologists, who used the data, proved to be mutually beneficial.

Lincoln remained in Washington, D.C., but retained administrative responsibility for the bird banding office through 1946. Management assistance at Patuxent was provided by May Thacher Cooke; two clerks, Marge Stewart and Lois Horn; biologist Chandler Robbins, beginning in 1943; and John Aldrich, who had transitional responsibilities between Lincoln's retirement and the appointment of Seth H. Low as the head of the bird banding office on January 5, 1948 (Steele, 1948; A.J. Duvall, 1968, unpublished letter on file at the U.S. Geological Survey Bird Banding Laboratory, Patuxent Wildlife Research Center, Laurel, MD).Low served in that capacity until 1954, when Allen J. Duvall transferred from the Museum of Natural History to PRR, where he was put in charge of migratory bird work, including the bird banding office. In a 1961 reorganization at Patuxent, the bird banding office was formally designated the Bird Banding Laboratory (BBL), and its leader, Duvall, was designated "Chief." Duvall remained BBL Chief until 1964, when he assumed a position with the Pesticides Review Board in Washington, D.C. The designations "BBL" and "Chief" remain today.

The internal written record of BBL's support for research during the tenures of Low and Duvall is relatively sparse, but that support was very likely given. Evidence exists in the form of external publications, notably two written by Aldo Leopold proteges Arthur S. Hawkins (1949) and Joseph J. Hickey (1952), who spent time at Patuxent researching the files at BBL.

Post-War Developments Influence Bird Banding

Outside the bird banding office during the late 1940s and 1950s, much was happening that would influence the office for decades to follow. As the Nation returned to "business as usual" after World War II, many young war veterans went to college under the Servicemen's Readjustment Act of 1944 (G.I. Bill), with increasing numbers entering the developing field of wildlife management. Surplus aircraft were made available for waterfowl surveys. Reliable funding from the Wildlife Restoration Act of 1937 (Pittman-Robertson Act) helped the States match the Federal Government's investment in waterfowl management. These efforts were stimulated by the resurgence of waterfowl hunting after G.I.s returned home and sporting ammunition became readily available. The development of cooperative bodies such as the four Flyway Councils furthered growth in waterfowl management. By 1960, State and Federal agencies were implementing cooperative, integrated, large-scale breeding ground surveys, harvest surveys, and banding programs specifically designed to yield data needed for waterfowl management. Martin and others (1979) and Hawkins and others (1984) provide interesting and comprehensive histories of these developments.

Seth Low, second chief of the Bird Banding Laboratory, Laurel, MD, 1951. Photo by Chandler S. Robbins, Patuxent Research Refuge.

Allen J. Duvall, third chief of the Bird Banding Laboratory, Laurel, MD, 1961. Photo by U.S. Fish and Wildlife Service.

Laverne Casteline checking schedules, Bird Banding Laboratory, Laurel, MD, 1951. Photo by U.S. Fish and Wildlife Service.

Waterfowl Concerns Dominate at the Bird Banding Laboratory during the 1950s and 1960s

During the 1950s and 1960s, Patuxent became a leader in developing and managing surveys that supported research on and management of migratory game birds. In a supporting role, the BBL followed suit. The BBL adopted permit and data policies that clearly favored game-bird banding. Operational procedures were developed to accommodate game-bird interests; for example, banding and recovery records were modified to include codes for flyways, and all recovery records contained a "hunting seasons survived" code, even for nongame birds. Large numbers of waterfowl being banded reflected the emphasis on game-bird banding, and soon the mallard (*Anas platyrhynchos*) became the most frequently banded bird in North America, a distinction that it holds to this day.

The BBL modernized data management in the early 1960s, partly to better serve research and management, and partly in response to a disastrous fire that destroyed many paper banding records in 1959. Chan Robbins explains that few records were actually lost in the fire, but all the punch cards were distorted or singed from the heat and had to be replaced (Chandler Robbins, U.S. Fish and Wildlife Service, oral commun., 1983). BBL staff and other Patuxent personnel spent approximately 2 years reconstructing the file after the fire. Entry into the newly emerging field of electronic data management was accelerated in the mid-1960s with the installation of a modern IBM® computer capable of managing the now millions of banding records being used by scientists at Patuxent and other locations. Added impetus to modernization efforts at the BBL arrived in late 1964 with the appointment of the engaging and energetic Earl B. Baysinger as the fourth BBL chief.

By the mid-1960s, the importance of the BBL's role in supporting research and management programs in the U.S. and Canada was recognized at the highest agency levels in Washington, D.C. In January 1967, the General Services Administration announced plans for the construction of a $1.1 million Bird Banding Records Center at Patuxent (The Washington Post, 1967). Construction was completed promptly, and in 1968 the BBL was housed in its new, state-of-the-art home named Gabrielson Laboratory (U.S. Fish and Wildlife Service, 1972) in honor of Ira N. Gabrielson, an accomplished ornithologist, conservationist, and former director of the USFWS. Gabrielson Laboratory offered far more space than the BBL needed, and therefore was soon filled by other offices, including the Migratory Bird Populations Station and a burgeoning computer section. The BBL remains housed in Gabrielson Laboratory at Patuxent to this day (2016).

New Analytical Models Begin to Influence Bird Banding

During the 1960s, a quiet, but profound, revolution in banding data analysis had begun outside the BBL and Patuxent with the development of the Jolly-Seber-Cormack models (Nichols and Tautin, 2008). Statistically, these models were vastly superior to the then commonly used life tables. Over the next four decades, these new models would lead to a tremendous expansion of analytical methods that would further validate the importance of banding data, and therefore the BBL, to research. As was historically the case with many developments in bird banding, this one also was driven by game-bird management priorities. Waterfowl management and the setting of annual hunting regulations was becoming more complex, and Federal and State agencies needed more accurate scientific results from banding (Tautin, 1993).

Helen Webster punching return card, Bird Banding Laboratory, Laurel, MD, 1951. Photo by U.S. Fish and Wildlife Service.

The availability of these statistically reliable models, particularly the so-called Seber-Robson-Brownie models for estimating survival and recovery rates from band recovery data (Brownie and Robson, 1976), led to the publication of the eight seminal "Mallard Reports" by Patuxent scientists (for example, Anderson and Burnham, 1976). In the 1970s, two of those scientists, David Anderson and Ken Burnham, moved from Patuxent to Colorado State University and collaborated with Gary White to produce many more reports related to the analysis of bird banding data. In testimony to their enduring contributions to wildlife conservation, all three later received the Aldo Leopold Award, the wildlife field's most prestigious honor.

Nongame-Bird Banding Comes of Age

During the 1970s and 1980s, game-bird considerations continued to dominate the banding program, but several events caused nongame-bird banding to become more prominent. The Endangered Species Act of 1973 formally gave the USFWS responsibility for threatened and endangered birds, most of which were nongame birds. Universities and colleges began to employ more ornithologists and, by the end of the 1980s, nearly one-third of all banders had an academic affiliation. Research centers like Patuxent devoted increasing attention to nongame-bird species. As evidenced by the many published reports cited in the other chapters in this volume, Patuxent in particular became renowned for its work with both endangered and nonendangered birds.

Institutional banders at Patuxent and in the broader ornithological community, having more scientific knowledge than nonprofessional banders, commonly used auxiliary markers such as colored leg bands, neck collars, and radio transmitters that yielded additional and more accurate data. The BBL worked closely with them to ensure that advanced marking techniques were both effective and safe for birds. For some widely studied species, the BBL also worked with banders and other stakeholders to develop cooperative marking protocols. These cooperative efforts led to a great increase in observations of marked birds that supported the use of analytical models, which had moved rapidly beyond game-bird band recovery models to include more versatile mark-recapture models well suited for nongame-bird studies.

Nongame-bird banding received an additional boost during the 1970s and 1980s after George Jonkel became the fifth BBL chief in 1971. Jonkel had been with the USFWS for many years, and had been an active bander of both game and nongame birds. Under Jonkel's leadership, the BBL encouraged and supported nongame-bird research by both professional and amateur banders, and maintained close ties to the amateur regional banding associations.

Furthermore, during this era and into the next millennium, BBL chiefs and staff biologists, themselves licensed bird banders, also lent "hands-on" support to banding projects at Patuxent and other banding places. Some examples were John Tautin's and B.H. Powell's tours of duty banding ducks in Canada under the cooperative prehunting-season banding program, Kathy Klimkiewicz's decade-long study of wintering birds, Danny Bystrak's long-term study of fall migrants on the Patuxent powerline right-of-way, Mary Gustaphson's operation of a constant effort banding station under the USFWS continent-wide Monitoring Avian Productivity and Survivorship program, and Bruce Peterjohn's study of hummingbirds.

Science Triumphs over the Challenge of Administrative Changes

In late 1988, John Tautin became the sixth BBL chief. Tautin, a bander and a career employee with the USFWS Office of Migratory Bird Management (MBMO), had worked as a biologist at the BBL during the mid-1970s. During his tenure, which lasted until 2002, the BBL faced difficult administrative challenges following its transfer from the USFWS to the newly created National Biological Survey (later Service; NBS) in 1993 and later to the U.S. Geological Survey in October 1996. Fortunately, during these transfers the BBL remained at Patuxent, where its close ties with research scientists and the MBMO helped ensure that it would continue to receive sufficient resources to remain functional.

John Tautin, sixth chief of the Bird Banding Laboratory, Laurel, MD. 2009. Photo by Tara Dodge, Purple Martin Conservation Association.

Kathy Klimkiewicz capturing white-breasted nuthatch with color-coded band, Patuxent Research Refuge, Laurel, MD, 1977. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

The importance of the BBL to research at Patuxent, and indeed to scientists across North America, was underscored in an extensive report (Buckley and others, 1998) by an external review panel commissioned by the NBS.

The review panel's report added impetus to ongoing efforts by the BBL to make the banding program more scientific. These efforts included re-engineering the BBL's database and computer operations, developing software for banders to manage and report banding data, designing a recapture/resighting database, and implementing a toll-free telephone number that people could call to report bird bands.

The internal efforts made by the BBL to improve the management of millions of banding records have typically gone unheralded, but their importance to Patuxent scientists and the broader ornithological community cannot be overstated. For example, banders commonly replace bands on long-lived birds when they recapture them. The bird then has two, if not more, unique band numbers assigned to it, causing a record-keeping problem. Over the years, without direction or fanfare, BBL biologists, clerks, and computer staff developed ever better procedures for processing replaced bands, enabling scientists to maintain continuous records of the birds. Without these procedures, tracking the remarkable life of 62-year-old Wisdom, an albatross originally banded by Patuxent's Chandler Robbins in 1956 and subsequently rebanded several times, would not have been possible.

Among the BBL's efforts to improve operations, the toll-free number was a particularly important and successful development. In a late 1980s study, Patuxent scientists (Nichols and others, 1991) had determined that only 32 percent of hunters who killed a banded mallard actually reported the band. This low rate was inadequate to supply input to the data-hungry analytical models and adaptive management principles being applied in an effort to develop a more scientific approach to setting hunting regulations. Providing hunters with a convenient toll-free number to call for band reporting was the ideal solution to the need for more and better band-recovery data. The availability of the toll-free number doubled the reporting rate in only a few years.

During all of these operational developments, the BBL directly supported many individual Patuxent research projects (for example, Spendelow and others, 1995) and strengthened ties with Patuxent scientists. Some of these scientists were world leaders in developing ever more sophisticated models for analyzing banding and other data, while also developing new approaches to science-based decision making. Patuxent scientists Byron (Ken) Williams, James Nichols, and Michael Conroy cite many examples of their work in the monumental publication "Analysis and Management of Animal Populations" (Williams and others, 2002). The BBL helped by publicizing the new analytical models, participating in international technical conferences held to advance the models (Tautin, 1993; Tautin and others, 1999), organizing analytical workshops at ornithological meetings, and otherwise encouraging bird banders to use these powerful new tools.

Tautin retired from Federal service in late 2002. Succeeding BBL chiefs Monica Tomosy (2003) and Bruce Peterjohn (2008) and their staff continued the BBL's support of research at Patuxent and across North America. After completing the initial re-engineering effort at the BBL, they expanded Web-based procedures that improved data collection and distribution; developed Bandit software, which improved the efficiency of submitting banding data for both the banders and the BBL; and developed Web-based band reporting procedures that cut costs and facilitated bird-band reporting by the public. The BBL also modernized permit policies and expanded support for bird banding in Latin America. And, as it had always done, during Tomosy and Peterjohn's tenures, the BBL continued to work with scientists from Patuxent and elsewhere to develop and apply advanced technology for bird studies, most notably the use of geolocator data loggers, which revolutionized studies of migratory songbirds in 2007 (Stutchbury and others, 2009).

The Patuxent Wildlife Research Center Looks Ahead

The transfer of the bird banding office to PRR in 1942 marked the beginning of a highly successful and mutually beneficial collaboration with research and management functions colocated there. So long as the BBL and Patuxent remain viable and continue to coordinate work, it is reasonable to assume that this remarkable 70-year legacy will continue. Maintaining this relationship is desirable because, as Paul Bartsch noted when bird banding first began in North America, "There are still many unsolved problems about bird life…."

References Cited

Anderson, D.R., and. Burnham, K.P., 1976, Population ecology of the mallard—VI. The effect of exploitation on survival: U.S. Fish and Wildlife Service, Resource Publication 128, 66 p.

Bartsch, Paul, 1904, Notes on the herons of the District of Columbia: Smithsonian Miscellaneous Collections, no. 1419, v. 45, p. 104–111.

Brownie, C., and Robson, D.S., 1976, Models allowing for age-dependent survival rates for band return data: Biometrics, v. 32, no. 2, p. 305–323. [Also available at http://dx.doi.org/10.2307/2529500.]

Buckley, P.A., Francis, C.M., Blancher, Peter, DeSante, D.F., Robbins, C.S., Smith, Graham, and Cannell, Peter, 1998, The North American bird banding program—Into the 21st century: Journal of Field Ornithology, v. 69, no. 4, p. 511–529. [Also available at https://sora.unm.edu/node/52264.]

Cole, L.J., 1922, Early history of bird banding in America: Wilson Bulletin, v. 34, no. 2, p. 108–114. [Also available at http://www.jstor.org/stable/4155031.]

Gabrielson, I.N., 1961, Obituary—Frederick Lincoln: Auk, v. 79, no. 3, p. 495–499. [Also available at https://sora.unm.edu/node/21142.]

Hawkins, A.S., 1949, Migration pattern in the mallard, *in* Aldrich, J.W., Hawkins, A.S., Addy, C.E., Jensen, G.H., Smith, A.G., Low, S.H., Stoudt, J.H., Robbins, C.S., Duvall, A.J., and Stewart, R.E., Migration of some North American waterfowl—A progress report on an analysis of banding records: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 1, p. 4–5.

Hawkins, A.S., Hanson, R.C., Nelson, H.K., and Reeves, H.M., eds., 1984, Flyways—Pioneering waterfowl management in North America: Washington, D.C., U.S. Department of the Interior, U.S. Fish and Wildlife Service, 517 p.

Hickey, J.J., 1952, Survival studies of banded birds: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 15, 177 p.

Jackson, J.L., 2008, The early history of bird banding in North America, *in* Jackson, J.A., Davis, W.E., Jr., and Tautin, John, eds., Bird banding in North America—The first 100 years: Cambridge, MA, Memoirs of the Nuttall Ornithological Club, no. 15, p. 1–30.

Lincoln, F.C., 1930, Calculating waterfowl abundance on the basis of banding returns: Washington, D.C., U.S. Department of Agriculture, Circular 118, 4 p. [Also available at https://ia801702.us.archive.org/31/items/calculatingwater118linc/calculatingwater118linc.pdf.]

Lincoln, F.C., 1935, The waterfowl flyways of North America: Washington, D.C., U.S. Department of Agriculture, Circular 342, 12 p. [Also available at https://archive.org/details/waterfowlflyways342linc.]

Martin, F.W., Pospahala, R.S., and Nichols, J.D., 1979, Assessment and population management of North American migratory birds, *in* Cairns, John, Patil, G.P., and Waters, W.E., eds., Environmental biomonitoring, assessment, prediction, and management—Certain case studies and related quantitative issues: Burtonsville, MD, International Coorperative Publication House, Statistical Ecology, v. S11, p. 187–239.

Nichols, J.D., Blohm, R.J., Reynolds, R.E., Trost, R.E., Hines, J.E., and. Bladen, J.P., 1991, Band reporting rates for mallards with reward bands of different dollar values: Journal of Wildlife Management, v. 55, no. 1, p. 119–126. [Also available at http://dx.doi.org/10.2307/3809248.]

Nichols, J.D., and Tautin, John, 2008, North American bird banding and quantitative population ecology, *in* Jackson, J.A., Davis, W.E., Jr., and Tautin, John, eds., Bird banding in North America—The first 100 years: Cambridge, MA, Memoirs of the Nuttall Ornithological Club, no. 15, p. 133–162.

Reeves, H.M., 1984, Portraits—Frederick C. Lincoln, *in* Hawkins, A.S., Hanson, R.C., Nelson, H.K., and Reeves, H.M., eds., Flyways—Pioneering waterfowl management in North America: Washington, D.C., U.S. Fish and Wildlife Service, p. 72–74.

Spendelow, J.A., Nichols, J.D., Nisbet, I.C.T., Hays, Helen, Cormons, G.D., Burger, Joanna, Safina, Carl, Hines, J.E., and Gochfeld, Michael, 1995, Estimating annual survival and movement rates of adults within a metapopulation of roseate terns: Ecology, v. 76, no. 8, p. 2415–2428. [Also available at http://dx.doi.org/10.2307/2265817.]

Steele, P.H., 1948, Washington notice: News from the bird-banders, v. 23, no. 2.

Stutchbury, B.J.M., Tarof, S.A., Done, T., Gow, Elizabeth, Kramer, P.M., Tautin, John, Fox, J.W., and Afanasyev, Vsevolod, 2009, Tracking long-distance songbird migration using geolocators: Science, v. 323, no. 5916, p. 896. [Also available at http://dx.doi.org/10.1126/science.1166664.]

Tautin, John, 1993, The influence of capture-recapture methodology on the evolution of the North American bird banding program, *in* Lebreton, J.D., and North, P.M., eds., Marked individuals in the study of bird population: Basel, Switzerland, Birkhauser Verlag, p. 185–196.

Tautin, John, 2005, Frederick C. Lincoln and the formation of the North American bird banding program, *in* Ralph, C.J., and. Rich, T.D., eds., Bird conservation implementation and integration in the Americas: Proceedings of the Third International Partners in Flight Conference, Asilomar, CA, March 20–24, 2002, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, General Technical Report GTR–PSW–191, p. 813–814. [Also available at http://www.fs.fed.us/psw/publications/documents/psw_gtr191/.]

Tautin, John, 2008, A history of the Bird Banding Laboratory—1920–2002, *in* Jackson, J.A.. Davis, W.E ., Jr., and Tautin, John, eds., Bird banding in North America—The first 100 years: Cambridge, MA, Memoirs of the Nuttall Ornithological Club, no. 15, p. 65–91.

Tautin, John, Metras, Lucie, and Smith, Graham, 1999, Large-scale studies of marked birds in North America, *in* Baillie, S.R., and North, P.M., eds., Large-scale studies of marked birds: Bird Study, no. 46, suppl. 1, p. S271–S278. [Also available at http://dx.doi.org/10.1080/00063659909477254.]

Terres, J.K., 1947, Big brother to the waterfowl: Audubon Magazine, v. 49, no. 3, p. 150–158.

The Washington Post, 1967, For the birds: The Washington Post, January 12, 1967, p. F2.

U.S. Fish and Wildlife Service, 1972, Population ecology of migratory birds: Washington, D.C., U.S. Fish and Wildlife Service, Wildlife Research Report 2, 278 p.

Wetmore, A.C., 1915, Mortality among waterfowl around Great Salt Lake, Utah: Washington, D.C., Bulletin of the U.S. Department of Agriculture, no. 217, 10 p. [Also available at http://dx.doi.org/10.5962/bhl.title.108397.]

Williams, B.K., Nichols, J.D., and Conroy, M.J., 2002, Analysis and management of animal populations (1st ed.): New York, Academic Press, 817 p.

G. Michael Haramis banding a male canvasback in Chesapeake Bay, 1978.
Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Patuxent's Role in the Development of the North American Breeding Bird Survey

John R. Sauer

The North American Breeding Bird Survey (BBS) is a roadside survey of the breeding birds of North America. The BBS provides data from the contiguous United States, Alaska, southern and central Canada, and northern Mexico. Begun in 1966 by Chandler (Chan) S. Robbins at the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center (Patuxent), and now jointly managed by Patuxent, the Canadian Wildlife Service, and the Mexican Commission for the Knowledge and Use of Biodiversity, the survey is conducted primarily in June along more than 5,000 roadside survey routes that are surveyed once each year. Volunteer observers drive the 39.4-kilometer (24.5-mile [mi]) routes, stopping approximately every 800 meters (m) (0.5 mi) to conduct fifty 3-minute point counts during which they record all the birds heard or seen within a 400-m (0.25-mi) radius of the counting location. Observers submit their data for each stop along their routes to the BBS offices in their respective countries, after which the information is made available to the public.

K.A. Smith and J. Rensel. Breeding Bird Survey volunteers, along historic intercontinental railroad grade on the Peplin Mountain, UY (Utah Breeding Bird Survey route 85251). Photo by U.S. Fish and Wildlife Service.

The BBS is unique in its temporal and geographic scale, and it is often the only source of information for geographic studies of important scientific issues such as the effects of climate change, disease, and land-use change on North American bird populations. Wildlife researchers and managers rely on the survey as the authoritative source of information on population change for more than 400 species of North American birds. It was the primary source of data for the State of the Birds Report (North American Bird Conservation Initiative, 2009), a publicly accessible summary of the "big picture" of population change and conservation of North American birds. Nevertheless, even after more than 45 years successfully providing population change data, Patuxent researchers are continuing their efforts to strengthen the BBS and similar surveys. Keeping a survey such as the BBS current in terms of field methods, data management, and analyses is a formidable task, and Patuxent has devoted substantial resources toward all of these activities throughout much of its existence. This chapter describes some of the themes and approaches to the design and analysis of roadside bird surveys that have been used at Patuxent, where the BBS and related surveys conducted by the U.S. Fish and Wildlife Service (USFWS) for mourning doves (*Zenaida macroura*) (the Call-Count Survey [CCS]; Sauer and others, 2010) and American woodcock (*Scolopax minor*) (the Singing-Ground Survey [SGS]; Sauer and others, 2008) have been the focus of research activity since the 1940s.

In this chapter, the term "Patuxent" is used in the "greater Patuxent" sense that Jim Kushlan used during his tenure as Patuxent's director—that is, the historical components that have been merged and divided over the years to become the current-day Patuxent Wildlife Research Center, as well as the colocated USFWS and other groups that once were part of entities such as the Migratory Bird Populations Station.

Background of the Breeding Bird Survey

The USFWS had a long history of bird population research before the initiation of the BBS. Roadside surveys of singing grounds of American woodcock were pioneered by Mendall and Aldous (1943), and became a standard approach for monitoring the species. Sheldon (1953) conducted studies to address the number, duration, and protocols for a stop-based roadside woodcock survey, and Kozicky and others (1954) conducted a statistical review of the approach, recommending random route locations. Chan Robbins helped analyze and summarize woodcock and mourning dove surveys during the 1950s, and participated in the preparation of status reports used in setting harvest regulations for these species. Although Chan had a great deal of experience with alternative bird counting approaches such as atlases, breeding bird censuses, Christmas Bird Counts (CBC), and roving censuses, he realized that the roadside survey had advantages over the alternatives as an efficient and relatively consistent way of collecting data over large areas. The method also had the advantage of having undergone a substantial evolution in approach and several methodological reviews while the USFWS was implementing the woodcock and dove surveys.

The critical difference between a nongame survey and the dove and woodcock surveys was that states were willing to devote resources to ensure adequate monitoring of harvested species, but no resources were available for nongame species. Consequently, when considering how to implement a North American breeding bird survey, Chan could not rely on the existing network of State personnel to conduct the counts. Fortunately, his birding activities provided him with a unique connection to the nationwide pool of birdwatchers. Chan was a major figure in birdwatching and, through State and regional bird clubs, the National Audubon Society, and a wide array of friends and colleagues throughout the continent, he envisioned staffing a survey that would utilize volunteers in the same way that the CBC had, but that would also have the rigor of the USFWS roadside surveys. Chan described his pioneering activities in developing the BBS in several presentations and publications (for example, Robbins and others, 1986; C.S. Robbins, U.S. Geological Survey, oral commun., 2006; Robbins, 2016). The reader is referred to these sources for Chan's first-hand account of his use of the environmental awareness spawned by Rachel Carson's work to establish the need for a nationwide breeding bird survey (see also Sauer, 2008).

Tending to the Survey: Research and Management of a Complex Survey

Chan Robbins wanted the BBS to be relevant, and recognized from the start that relevance would require (1) designing a survey that would provide credible information; (2) implementing the survey efficiently in terms of the logistics of recruiting the observers and providing support in the form of information (data forms, maps) and communications (a labor-intensive task in the 1960s); (3) managing data (also very labor intensive); and (4) analyzing and effectively presenting the results. These needs are reflected in Chan's early requests for volunteers (Robbins, 1965b) and his prompt summary of the data (Robbins, 1965a). Because availability of and access to results as well as timely feedback to observers are critical aspects of a successful survey, Chan presented the summarized results on maps to facilitate the public's appreciation of the data (fig. 1; Robbins, 1965a).

The scope and goals of the BBS are extremely ambitious, and constant research and innovation are needed to keep pace with technological advances and maintain the credibility of the survey. Research associated with the survey has been a focus of field and statistical work at Patuxent over the past 45 years. The sections below summarize some of this research and describe how it has enhanced the value of the survey. They are organized in parallel with the essential elements of a successful survey listed above, but focus particularly on

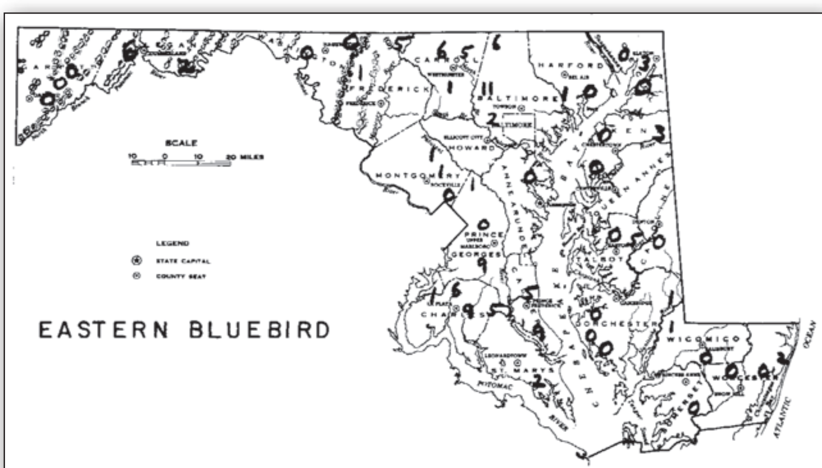


Figure 1. Eastern bluebird (*Sialia sialis*) counts for Maryland from the 1965 Breeding Bird Survey test run. (From Robbins, 1965a)

features 2 and 4 (survey implementation and communication of results), both of which are traditional functions of research that have been an important component of Patuxent for the duration of the survey.

Survey Design

Chan designed the survey to be consistent with the general approaches used by the CCS and SGS. As both of these surveys were used by management and had been tested through years of critical review and methods development, they were a good model for a logistically feasible survey that provided relevant data. Chan also conducted a variety of methodological studies in 1965 to evaluate specific aspects of the design, such as duration of counts and number of stops along the roadside routes (Robbins and others, 1986). From the start, however, Patuxent researchers criticized two important aspects of the survey. First, roadsides constitute an incomplete framework for sampling, as off-road habitats are not covered. Second, no observers count all the birds on a BBS route, and the proportion of birds missed in counting varies by species, observer, environmental conditions, date, time of day, and many other variables. Quantitative researchers at Patuxent in the 1960s were particularly critical of the BBS design, and vigorous arguments occurred about the need to conduct off-road counts and to collect additional data to control for variations in rates of bird detection (Charles Henny, U.S. Fish and Wildlife Service, oral commun., 1965). These issues have been the focus of much research at Patuxent over the past 40 years.

The question of whether the BBS needs to incorporate methods that allow estimation of rates of bird detection was, and still is, particularly controversial at Patuxent. Detectability estimation from count-based surveys has been a productive research area for Patuxent investigators, and many current and former Patuxent staff members have made important contributions in this area; all of the methods considered as possible approaches for adding detection rates to the BBS have been the subject of Patuxent studies. Patuxent alumni David Anderson and Kenneth Burnham, along with many students, have promoted line transect and capture-recapture methods for estimating detection rates of birds and other taxa.

At Patuxent, James Nichols and colleagues pioneered the use of capture-recapture and other approaches for analyzing count data to estimate species occupancy, abundance, and species richness. Andy Royle and colleagues described and implemented innovative ways of estimating detection rates from replicate surveys. William Link, William Kendall, and others addressed the question of detectability from a different perspective, considering it to be a feature of known covariates (such as the observer running the route), and modeling and controlling for these covariates in the analysis. Other quantitative ecologists, notably Ted Simons, Kenneth Pollock, and colleagues at North Carolina State University (Raleigh), have continued method development and conducted field trials to implement approaches for estimating detection rates. Finally, in his dual role as State BBS coordinator in Mississippi and Patuxent researcher, Daniel Twedt has implemented a pilot project to test the applicability of some of the field methods for estimating detectability along routes established in the Gulf Coast Network of national parks.

Most of these studies have included enthusiastic participation by field-oriented researchers and BBS coordinators, including (among many others) Patuxent biologists Chan Robbins, Deanna Dawson, Barbara Dowell, Daniel Boone, Danny Bystrak, Sam Droege, Bruce Peterjohn, Keith Pardieck, Jane Fallon, and David Ziolkowski. The volunteer BBS observers have also been more than willing to donate their time to participate in studies that use BBS routes as sample units, permitting regional analysis. This involvement of a large number of Patuxent staff members and volunteers is a model for collaborative science.

Evaluation of the consequences of the roadside nature of counts has also invoked the collaborative spirit of Patuxent staff members, most notably in a U.S. Environmental Protection Agency-funded study, in which data were collected both on survey routes and on nearby off-road routes. This study documented differences in species abundance on and off roads (Sauer and others, 2013). Another approach to addressing this question over the years has been to evaluate habitat differences between on- and off-road routes, first from aerial photographs (Keller and Scallan, 1999), then from interpreted Landsat data (National Land Cover Data [NLCD]) (Vogelmann and others, 2001) (Sauer and others, 2013; fig. 2).

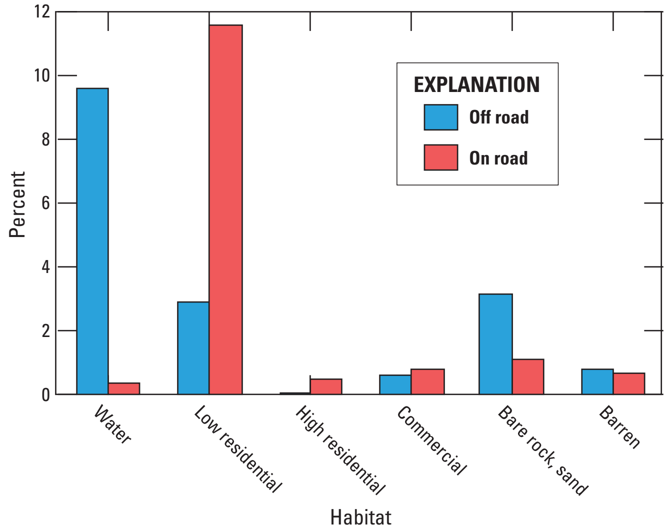


Figure 2. Percentages of six habitats near roads (at sampling sites within 400 meters [0.25 miles] of Breeding Bird Survey routes) and off roads (at sampling sites more than 400 meters from roads) in a study conducted in Maryland. (Data from Keller and Scallan, 1999; Sauer and others, 2013)

NLCD data provide excellent opportunities to evaluate habitats (fig. 3); several investigators have used them to assess whether habitats differ between on- and off-road routes (for example, Veech and others, 2012), or even to assess differences in rates of change in habitats between on- and off-road routes (Hanan, 2009). These studies have not shown major differences in habitats or rates of change in habitats between on- and off-road routes, although they have revealed that some habitats appear to be found more frequently near (for example, residential housing) or away from (for example, water) roads.

Survey Analysis and Presentation

Several themes emerge with respect to the history of the BBS. The first is that improvements in BBS analysis commonly were made possible by advances in computational technology. Early on in the BBS program, Patuxent's computers were not adequate to conduct analyses. Enormous amounts of time were spent trying to develop methods that could be used with the available computers, and the methods that ultimately were used to summarize BBS data typically were only approximations of the desired estimation. This limitation was more

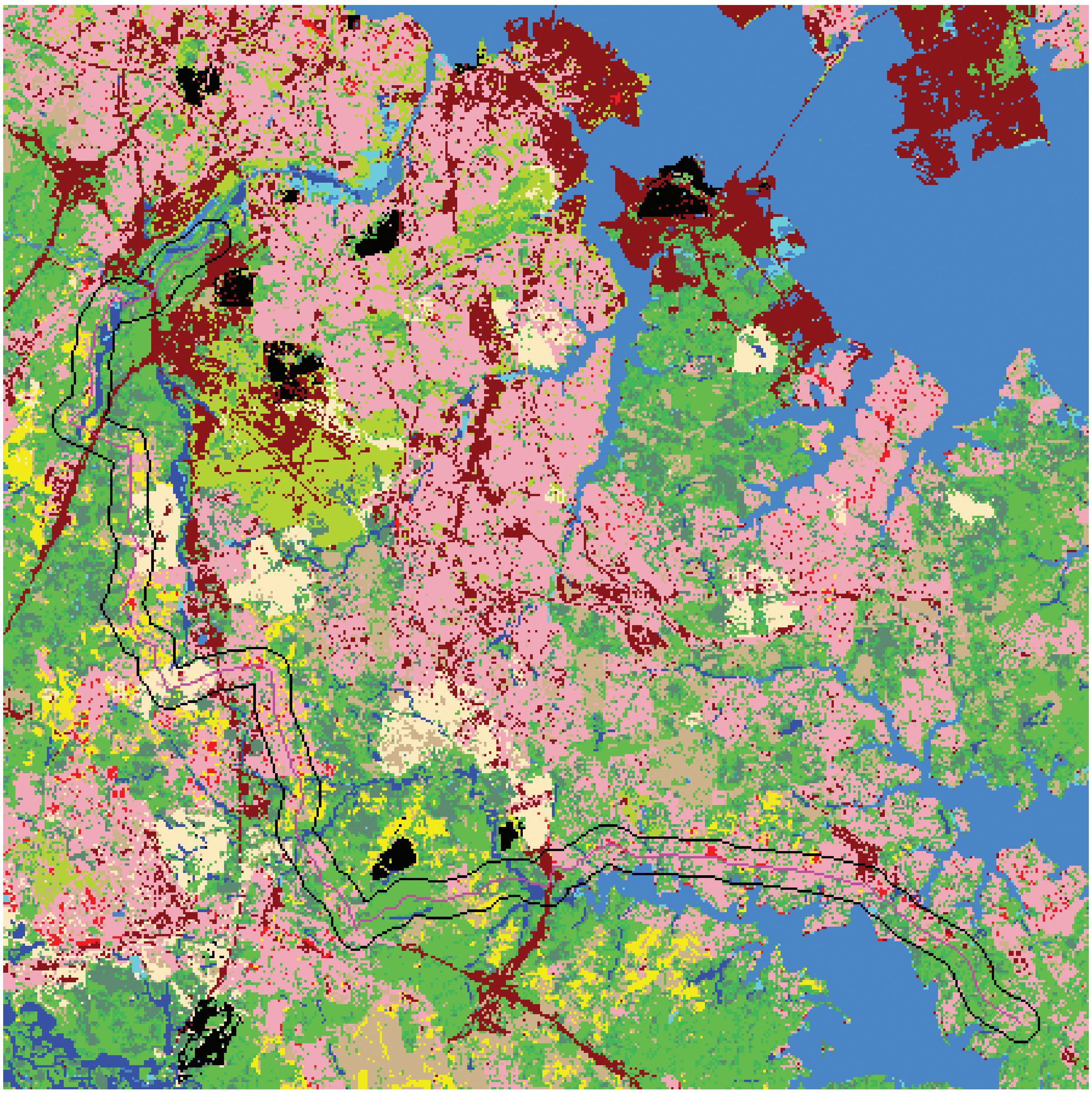


Figure 3. Severna Park, MD, Breeding Bird Survey route path (buffered at 400 meters [0.25 miles]) superimposed on National Land Cover Database (Vogelmann and others, 2001). (From U.S. Geological Survey, n.d.; map metadata accessed March 25, 2015, at http://www.mbr-pwrc.usgs.gov/bbs/trend/rtehtm13a_nlcd.html)

than just a computer issue, as new and increased computing capabilities expanded the space for and generated statistical innovation. This was clearly the case in BBS analyses.

A second theme is that innovation in methods at Patuxent has always been a collaborative effort, facilitated by the presence of mathematical statisticians, statistician/programmers, and biologists, all of whom work together to adapt existing computational resources to research needs, develop new approaches to analysis that can fully use new technology, and track emerging technologies for use in BBS analyses. This collaboration has been particularly important in terms of the deeper statistical aspects of estimation of population change, and Patuxent has been fortunate that a mathematical statistician with a focus on count surveys has been directly involved in analyzing BBS data. This involvement has paved the way to innovations such as estimating equations and hierarchical models, and has provided the expertise needed to apply the computer-intensive Bayesian statistical approaches that represent the current analysis paradigm.

The third theme is long-term participation by scientists. Consistent support for the program has led to great institutional memory and long-term stewardship of the survey. Chan Robbins has been present from the start; Danny Bystrak, Sam Droege, and Bruce Peterjohn are all former BBS coordinators working at Patuxent and are still active in the program, and collectively Paul Geissler, Bill Link, and I (John Sauer) have participated in the analysis of BBS data through 30 years. Consequently, data analysts have the great advantage of being able to talk to the people who actually designed the survey, managed the data, and conducted earlier analyses.

Three Analytical Approaches

Analysis of BBS data is difficult because (1) the survey has a very large geographic scope; (2) survey routes vary greatly in consistency of coverage within and among regions; (3) the counting abilities of different observers, even those judged to be competent birders, can differ greatly; and (4) modeling change through time is fundamentally controversial, even without these other factors. Consequently, all serious analyses of these data attempt to address these four characteristics of BBS data analysis, and many methods have been developed to control and model this "unruly" dataset. Moreover, many investigators download BBS data and conduct summary analyses that ignore one or more of these inherent characteristics of the dataset. Evaluating these analyses and, if necessary, controlling for them has been an ongoing concern for Patuxent scientists.

BBS analysis conducted at Patuxent during the period 1966–2013 can generally be placed into one of three "paradigms," each of which takes an alternative approach to accommodating these concerns by using statistical methods and computing technologies available at the time they were used. Placed in temporal order, the paradigms are (1) fairly simple summary analyses that relied on estimating regional change between adjacent years as ratios of comparable counts on routes and portraying them as scaled changes from some base year; (2) route-regression approaches, in which route-specific trends are used as replicates for estimating change; and (3) hierarchical models that use Bayesian methods to fit log-linear models with year effects.

Base Year Methods

Base year methods were used to analyze data from roadside surveys for American woodcock and mourning dove well before the initiation of the BBS, and are described in the scientific reports that provided summary results to managers (for example, Robbins, 1960; Kiel, 1960). The methods described in these reports show the essential components of a regional analysis. Within a region, computation of estimated change between adjacent years was estimated by using routes surveyed by the same observer, and the composite change over a longer interval was determined by multiplying a series of yearly change estimates by an estimated mean count in a base year. These indexes of change from the base year described an estimated composite time series for the region. Change for groups of regions was calculated by using an area-weighted average of the indexes from the component regions (Kiel, 1960).

Early summaries of BBS data show these general ideas, but also show a variety of alternative summaries as Chan and his colleagues explored the possibilities of summarizing North American bird population change (for example, Robbins and Van Velzen, 1969, 1974). Unfortunately, analysis of BBS data, which included data from more than 500 species of North American birds collected on thousands of survey routes distributed over both the United States and southern Canada (fig. 4), proved to be very challenging. Many species were encountered only infrequently on routes, observers tended to differ greatly in quality of information, not all routes were surveyed, and the expansion of the survey into new regions resulted in data that were very unequally distributed in space and time. Analysts were greatly constrained in the types of analyses that could be conducted, and cost was typically an issue, limiting the ability to apply complicated linear models. Computing proportional changes on comparable routes from a base year was relatively simple and could be readily implemented for BBS data.

Route Regression Approaches

Geissler and Noon (1981) provide a comprehensive summary of the analysis of the BBS through the 1970s. They acknowledge the need to control for differing routes used in change estimation, but identify several statistical concerns associated with the base year approach of multiplying mean counts from some initial year by yearly changes based on

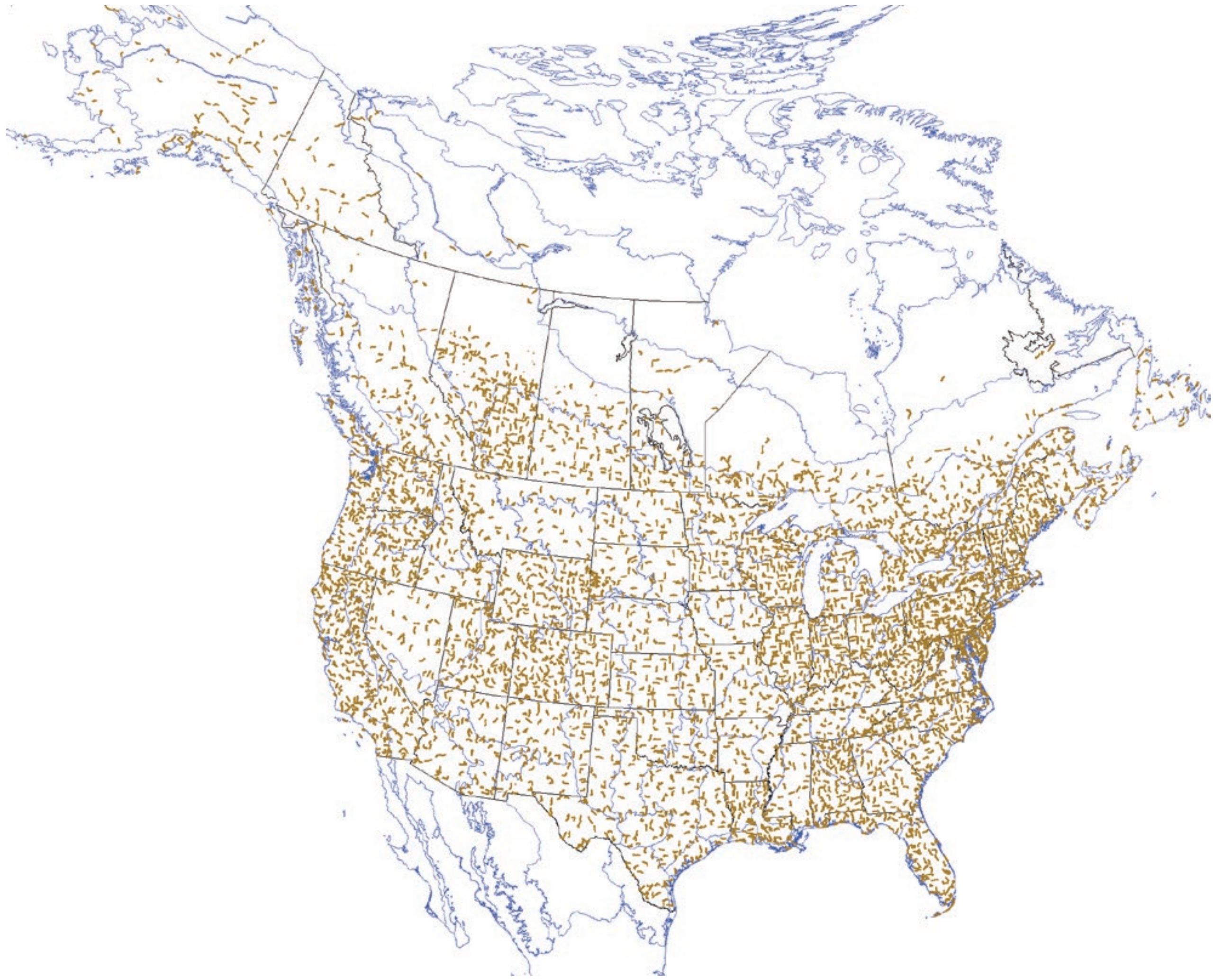


Figure 4. North American Breeding Bird Survey route locations. (From Sauer and others, 2013; note limited density of locations in northern and western regions; map metadata accessed March 25, 2015, at http://www.mbr-pwrc.usgs.gov/bbs/geographic_information/GIS_shapefiles_2013.html)

comparable routes. They instead suggest a "route regression" analysis, in which change is estimated by using regression analysis (log counts as a function of years) on individual routes, and then combined in a weighted average to form a regional composite estimate of change. The advantage of this approach is that observer differences can be controlled for in the analysis by including observer information as a covariate. Route regression methods were implemented for the survey and used in the 15-year summary of the BBS (Robbins and others, 1986), an important summary of the survey. Paul Geissler, a key figure in its development, did an admirable job of developing a robust analysis that could be applied to almost any BBS dataset.

The route regression method, with several modifications, was used as the primary BBS analysis method from 1986 to 2008. Like the base year method, route regression analyses could be implemented with relatively limited computer resources. It was a robust approach in that it could be implemented for almost any dataset, no matter how unbalanced with respect to patterns of years when routes were surveyed. Unfortunately, this adaptability had a cost in terms of limited capability for inference, and aspects such as the precision weightings that were criticized as being extemporaneous (Sauer and Link, 2011). With this complicated weighted average, no overall model could form a framework for estimation; variances needed to be calculated through bootstrapping, a tedious nonparametric procedure. Route regression produced a summary of interval-specific trend, but many people wanted more information—at least a graph showing population indices by year. Sauer and Geissler (1990) suggested an approach for estimating composite yearly indices of abundance that summarized the pattern around the trend line, but estimating variances of these annual indices was not possible.

Paul Geissler weathered a great deal of criticism before the route regression method was accepted, and it underwent periodic review and modification throughout the time of its use. Concerns about estimation of change on routes done by using simple regression on log counts was addressed in 1994, when Link and Sauer (1994) suggested using estimating equations to estimate trend on routes. However, the limited nature of the trend summaries, and the advent of methods that permitted comprehensive summaries with variances from the data, ultimately led to the replacement in 2008 of the route regression method with a hierarchical model.

Hierarchical Models

In 2002, Link and Sauer (2002) suggested the use of a log-linear hierarchical model for analysis of BBS data. Hierarchical models are a flexible means of modeling complex, multiscale longitudinal surveys such as the BBS. Attributes can be estimated at different scales (for example, routes, strata, continent-wide); the repeated nature of counts within survey routes can be modeled; nuisance factors such as differences in counting ability among observers and observer start-up effects can be controlled for; and year effects can be treated as random and estimated even when some years are poorly sampled (again, a common issue in the BBS). Most important, the model can be fit by using Markov chain Monte Carlo, an extremely computer-intensive method that became accessible to the scientific community when the software program WinBUGS (Lunn and others, 2000) was released in 1989. These methods require a Bayesian approach to statistics, in which all quantities are random and, rather than providing estimates of unknown fixed parameters, the goal of inference is to estimate the distributions of unknown (but variable) quantities of interest. Bayesian methods have an appealing conceptual simplicity and avoid the nuanced discussions that commonly afflict standard (non-Bayesian, or "Frequentist") statistical inference; they also have the great practical advantage of providing the only way to develop a comprehensive statistical framework for estimating population change from BBS data.

Bill Link became interested in these methods when he was developing approaches for summarizing collections of species trends (that is, how many species are increasing in population), and it became evident that Bayesian methods were a natural approach for estimating BBS and other data. He gradually became an important proponent of the use of these methods in ecological statistics (for example, Link and Barker, 2010).

Sauer and Link (2011) published a comprehensive comparative analysis of population change using these hierarchical models in 2011, and routinely continue to provide hierarchical model results to users. One great advantage of hierarchical models is their extreme flexibility. They provide a basis for an infinite number of elaborations, and users can associate attributes with population relative abundance and change at any scale of interest. They also can include submodels to accommodate observational components such as detectability.

Maps of Breeding Bird Survey Data

The benefits of the visual display of BBS data have long been obvious. Chan Robbins (1965a) made simple maps by writing numbers of birds encountered on routes in Maryland from the 1965 test survey (fig. 1); Danny Bystrak qualitatively estimated contour lines for maps in a summary of the BBS's first 15 years (Robbins and others, 1986) and other publications. By 1995, Patuxent was producing contour maps from surfaces based on Kriging and other surface modeling procedures (Sauer and others, 1995). Currently (2016), inverse-distance maps of both trend and abundance are made for more than 420 bird species (fig. 5). More sophisticated approaches such as hierarchical models have been implemented for selected species, but are not routinely applied to BBS data (Thogmartin and others, 2004).

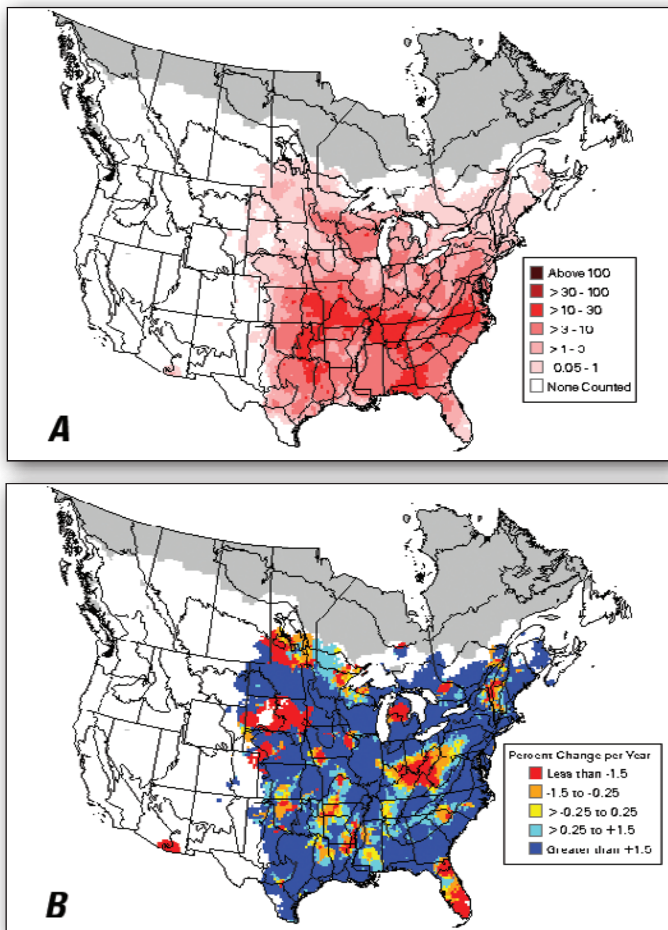


Figure 5. *A*, Relative abundance (summer distribution), 2006–10, and *B*, population change (trend) of Eastern bluebirds (*Sialia sialis*) in the 1966–2010 Breeding Bird Survey (BBS) analysis. (From Sauer and others, 2011; accessed February 16, 2011, at *A*, http://www.mbr-pwrc.usgs.gov/bbs/ra2010/ra7660.htm and *B*, http://mbr-pwrc.usgs.gov/bbs/tr2010/tr07660.htm; gray areas are regions outside the BBS area)

Internet-Based Summaries

In 1997, Patuxent began providing comprehensive summaries of BBS data to users on the World Wide Web (WWW) (Sauer and others, 1997). Jim Hines and I had been developing a stand-alone, PC (personal computer) -based program for summary and display of population trends, annual indices, and abundance and trend maps that we called program VUBBS. The material we had been producing was easily converted to the HyperText Markup Language (html) format that is still (2016) a primary means of displaying WWW content on browsers. Many of the results were prepackaged; we conducted the analysis, reviewed the results for consistency and correctness, and then provided interactive lists from which users could select species data for display. Because the results are served from a computer at Patuxent, we had great flexibility to develop new summaries by means of Perl scripts and other programs that allowed users to run programs on Patuxent's computers. In this way, users could estimate population trends interactively for any species using predefined regions. These online summary results are revised annually, are available to any user, and have proven to be effective tools for bird conservation (figs. 6 and 7).

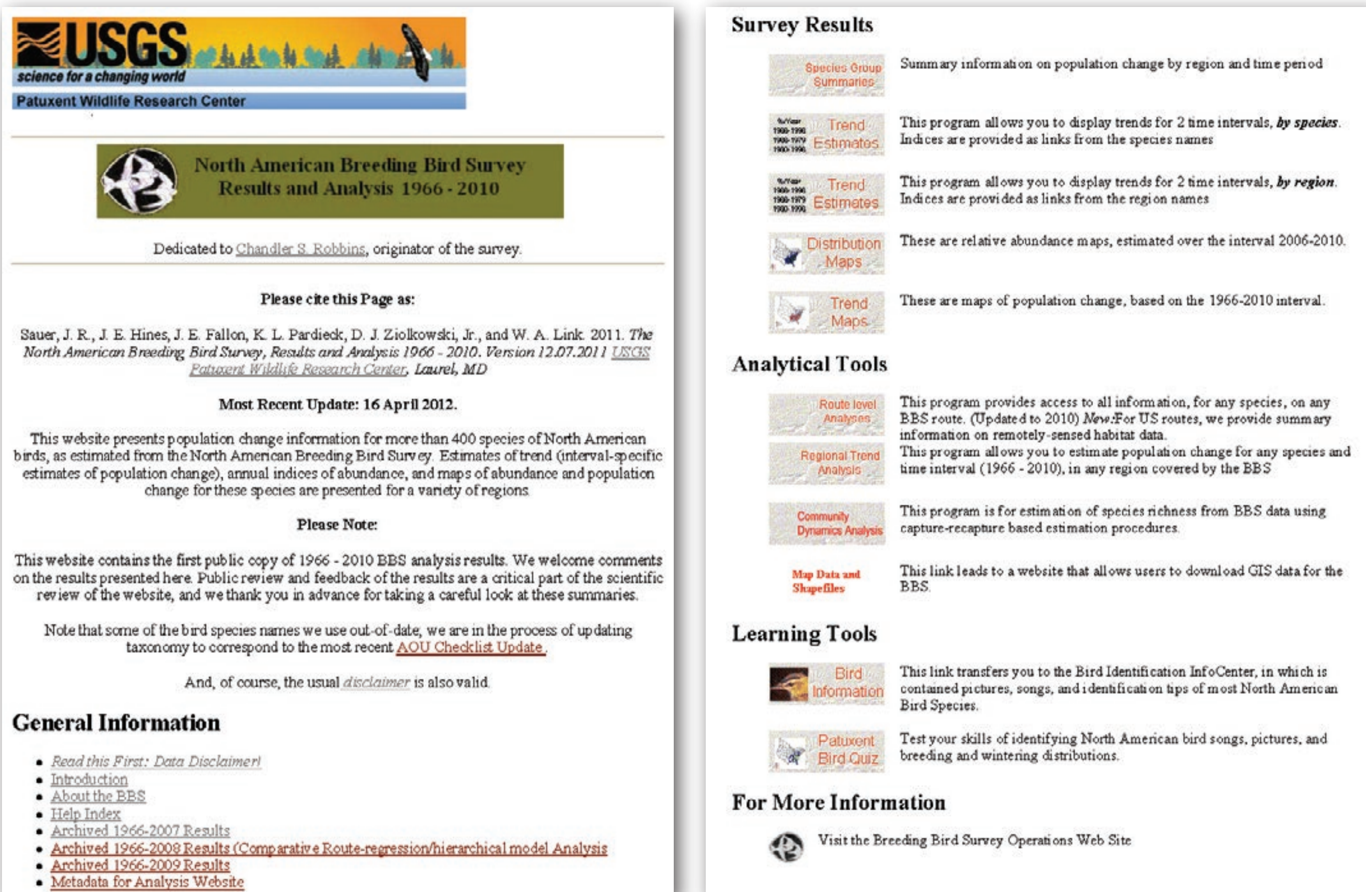
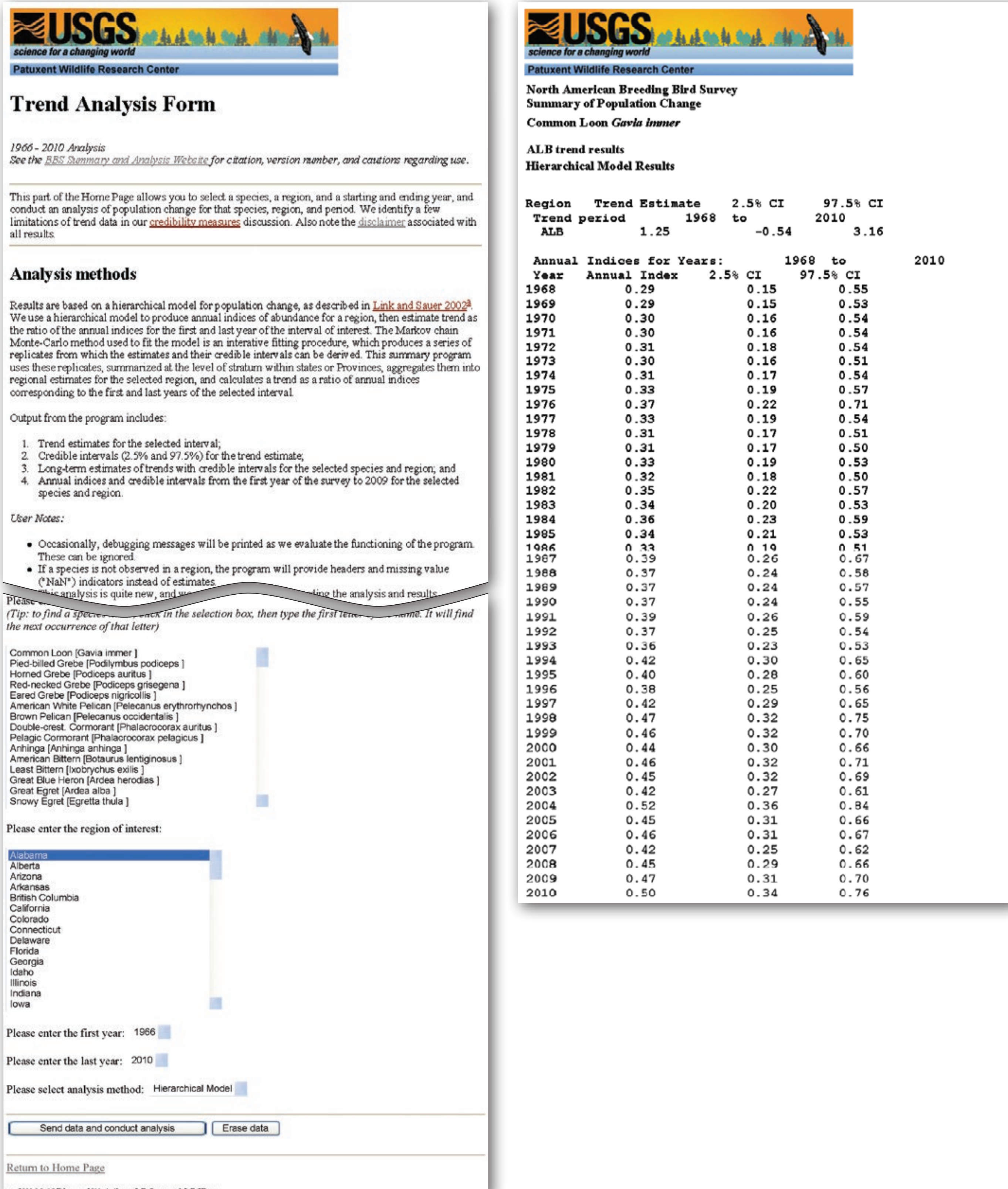


Figure 6. Screen capture of the home page of the North American Breeding Bird Survey results and analysis Web site, 1966–2010. (From Sauer and others, 2011)



USGS science for a changing world

Patuxent Wildlife Research Center

Trend Analysis Form

1966 - 2010 Analysis
See the BBS Summary and Analysis Website *for citation, version number, and cautions regarding use.*

This part of the Home Page allows you to select a species, a region, and a starting and ending year, and conduct an analysis of population change for that species, region, and period. We identify a few limitations of trend data in our credibility measures discussion. Also note the disclaimer associated with all results.

Analysis methods

Results are based on a hierarchical model for population change, as described in Link and Sauer 2002[a]. We use a hierarchical model to produce annual indices of abundance for a region, then estimate trend as the ratio of the annual indices for the first and last year of the interval of interest. The Markov chain Monte-Carlo method used to fit the model is an interative fitting procedure, which produces a series of replicates from which the estimates and their credible intervals can be derived. This summary program uses these replicates, summarized at the level of stratum within states or Provinces, aggregates them into regional estimates for the selected region, and calculates a trend as a ratio of annual indices corresponding to the first and last years of the selected interval.

Output from the program includes:

1. Trend estimates for the selected interval;
2. Credible intervals (2.5% and 97.5%) for the trend estimate;
3. Long-term estimates of trends with credible intervals for the selected species and region; and
4. Annual indices and credible intervals from the first year of the survey to 2009 for the selected species and region.

User Notes:

- Occasionally, debugging messages will be printed as we evaluate the functioning of the program. These can be ignored.
- If a species is not observed in a region, the program will provide headers and missing value ("NaN") indicators instead of estimates.
- This analysis is quite new, and we ... ding the analysis and results.

Please ...
(Tip: to find a species ... click in the selection box, then type the first lette... name. It will find the next occurrence of that letter)

Common Loon [Gavia immer]
Pied-billed Grebe [Podilymbus podiceps]
Horned Grebe [Podiceps auritus]
Red-necked Grebe [Podiceps grisegena]
Eared Grebe [Podiceps nigricollis]
American White Pelican [Pelecanus erythrorhynchos]
Brown Pelican [Pelecanus occidentalis]
Double-crest. Cormorant [Phalacrocorax auritus]
Pelagic Cormorant [Phalacrocorax pelagicus]
Anhinga [Anhinga anhinga]
American Bittern [Botaurus lentiginosus]
Least Bittern [Ixobrychus exilis]
Great Blue Heron [Ardea herodias]
Great Egret [Ardea alba]
Snowy Egret [Egretta thula]

Please enter the region of interest:

Alabama
Alberta
Arizona
Arkansas
British Columbia
California
Colorado
Connecticut
Delaware
Florida
Georgia
Idaho
Illinois
Indiana
Iowa

Please enter the first year: 1966

Please enter the last year: 2010

Please select analysis method: Hierarchical Model

Send data and conduct analysis | Erase data

Return to Home Page

ver 2011.0.0, 16 February 2011, Authors: J. R. Sauer and J. E. Hines.

USGS science for a changing world

Patuxent Wildlife Research Center

North American Breeding Bird Survey
Summary of Population Change
Common Loon *Gavia immer*

ALB trend results
Hierarchical Model Results

Region	Trend Estimate	2.5% CI	97.5% CI
Trend period	1968	to	2010
ALB	1.25	-0.54	3.16

Annual Indices for Years: 1968 to 2010

Year	Annual Index	2.5% CI	97.5% CI
1968	0.29	0.15	0.55
1969	0.29	0.15	0.53
1970	0.30	0.16	0.54
1971	0.30	0.16	0.54
1972	0.31	0.18	0.54
1973	0.30	0.16	0.51
1974	0.31	0.17	0.54
1975	0.33	0.19	0.57
1976	0.37	0.22	0.71
1977	0.33	0.19	0.54
1978	0.31	0.17	0.51
1979	0.31	0.17	0.50
1980	0.33	0.19	0.53
1981	0.32	0.18	0.50
1982	0.35	0.22	0.57
1983	0.34	0.20	0.53
1984	0.36	0.23	0.59
1985	0.34	0.21	0.53
1986	0.33	0.19	0.51
1987	0.39	0.26	0.67
1988	0.37	0.24	0.58
1989	0.37	0.24	0.57
1990	0.37	0.24	0.55
1991	0.39	0.26	0.59
1992	0.37	0.25	0.54
1993	0.36	0.23	0.53
1994	0.42	0.30	0.65
1995	0.40	0.28	0.60
1996	0.38	0.25	0.56
1997	0.42	0.29	0.65
1998	0.47	0.32	0.75
1999	0.46	0.32	0.70
2000	0.44	0.30	0.66
2001	0.46	0.32	0.71
2002	0.45	0.32	0.69
2003	0.42	0.27	0.61
2004	0.52	0.36	0.84
2005	0.45	0.31	0.66
2006	0.46	0.31	0.67
2007	0.42	0.25	0.62
2008	0.45	0.29	0.66
2009	0.47	0.31	0.70
2010	0.50	0.34	0.76

Figure 7. Screen capture of Web site showing an example of the results obtained by using the interactive program for summarizing population change from North American Breeding Bird Survey data (http://www.mbr-pwrc.usgs.gov/bbs/trend/tf11.html, accessed February 16, 2011). The program is shown in the left and center columns; the right column shows a results summary for Common Loons (*Gavia immer*) in Alberta, Canada.

A "Living" Survey (Past, Present, and Future)

The BBS, like any survey, can never be considered a finished product, but must be subject to modification to incorporate new ideas and address newly discovered (or even long-term) deficiencies. Patuxent researchers have focused on improving the analysis of this important survey, conducting field studies on the process of counting birds (for example, Keller and Fuller, 1995), and evaluating the consequences of detectability and roadside survey constraints. In addition, Patuxent has made the survey and analyses increasingly accessible to the scientific community through computer programs and technical support. Many researchers use BBS data, and their analyses often generate new ideas and raise (or quell) concerns about the survey. Making the survey analytical results and tools available facilitates that work. The interactive analysis program on the Breeding Bird Survey Web site (http://www.mbr-pwrc.usgs.gov/bbs/bbs.html, accessed February 16, 2011), for example, allows users to select data by region and period for analysis. This interaction between the organization that conducts the survey and the community that uses the survey data is critical for the long-term sustainability of the survey, as it maintains a focus on ascertaining and meeting user needs.

Patuxent has long taken a leadership role in summarizing this important survey. The key to the survey's success is constant revision and research input into the "routine" yearly summaries of the data. Another key component of this success is the mutual respect and collaborative research skills of the BBS staff members, ranging from ornithologists, who inform the analysis with natural history and taxonomic information; to computer programmers, who provide the programming skills and Internet expertise to allow implementation of analysis and summary programs; to mathematical statisticians, who authoritatively navigate the increasingly complicated methods now employed for BBS data analysis. Although administrators may, at times, underestimate the value of statistical analysis in ecological research and relegate statisticians to a supporting role, such a philosophy could undermine the success of a complex and evolving survey such as the BBS. BBS researchers have been fortunate over the years that Patuxent's administrators have recognized that the effective running and maintenance of the survey requires a collaborative partnership.

References Cited

Geissler, P.H., and Noon, B.R., 1981, Estimates of avian population trends from the North American Breeding Bird Survey, *in* Ralph, C.J., and. Scott J.M., eds., Estimating numbers of terrestrial birds: Lawrence, KS, Studies in Avian Biology, v. 6, p. 42–51. [Also available at https://sora.unm.edu/sites/default/files/journals/sab/sab_006.pdf.]

Hanan, M.D., 2009, Land cover change and the breeding bird survey—Rates of change in relation to roads: Brookings, SD, South Dakota State University, M.S. thesis, 170 p. [Also available at http://pubstorage.sdstate.edu/wfs/thesis/Hanan-Michael-D-M-S-2009.pdf.]

Keller, C.M.E., and Fuller, M.R., 1995, Comparison of birds detected from roadside and off-road point counts in the Shenandoah National Park, *in* Ralph, C.J., Sauer, J.R., and Droege, Sam, eds., Monitoring bird populations by point counts: Albany, CA, U.S. Forest Service, General Technical Report PSW–GTR–149, p. 111–115. [Also available at http://www.fs.fed.us/psw/publications/documents/gtr-149/pg111_116.pdf.]

Keller, C.M.E., and Scallan, J.T., 1999, Potential roadside biases due to habitat changes along Breeding Bird Survey routes: Condor, v. 101, no. 1, p. 50–57. [Also available at http://dx.doi.org/10.2307/1370445.]

Kiel, W.H., 1960, Mourning dove status report–1960: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 49, p. 1–34.

Kozicky, E.L., Bancroft, T.A., and Homeyer, P.G., 1954, An analysis of woodcock singing ground counts, 1948–1952: Journal of Wildlife Management, v. 18, no. 2, p. 259–266. [Also available at http://dx.doi.org/10.2307/3797724.]

Link, W.A., and Barker, R.J., 2010, Bayesian inference with ecological applications: New York, Academic Press, 338 p.

Link, W.A., and Sauer, J.R., 1994, Estimating equations estimates of trends: Bird Populations, v. 2, p. 23–32.

Link, W.A., and Sauer, J.R., 2002, A hierarchical analysis of population change with application to cerulean warblers: Ecology, v. 83, no. 10, p. 2832–2840. [Also available at http://dx.doi.org/10.1890/0012-9658(2002)083[2832:AHAOPC]2.0.CO;2.]

Lunn, D.J., Thomas, Andrew, Best, Nicky, and Spiegelhalter, David, 2000, WinBUGS—A Bayesian modelling framework—Concepts, structure, and extensibility: Statistics and Computing, v. 10, no. 4, p. 325–337. [Also available at http://dx.doi.org/10.1023/A:1008929526011.]

Mendall, H.L., and Aldous, C.M., 1943, The ecology and management of the American woodcock: Orono, ME, Maine Cooperative Fish and Wildlife Research Unit, University of Maine, 201 p.

North American Bird Conservation Initiative, U.S. Committee, 2009, The state of the birds, United States of America: Washington, D.C., U.S. Department of the Interior, 36 p.

Robbins, C.S., 1960, Woodcock status report, 1960: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 50, 26 p.

Robbins, C.S., 1965a, Fifty thousand birds recorded on Breeding Bird Survey: Maryland Birdlife, v. 21, no. 3, p. 73–79. [Also available at https://sora.unm.edu/node/132783.]

Robbins, C.S., 1965b, New Breeding Bird Survey tested in Maryland this summer: Maryland Birdlife, v. 21, no. 2, p. 48–49. [Also available at https://sora.unm.edu/node/132782.]

Robbins, C.S., 2016, Early avian studies at Patuxent, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 13–24. [Also available at https://doi.org/10.3133/cir1422.

Robbins, C.S., Bystrak, Danny, and Geissler, P.H., 1986, The Breeding Bird Survey—Its first fifteen years, 1965–1979: Washington, D.C., U. S. Fish and Wildlife Service, Resource Publication 157, 196 p. [Also available at http://pubs.usgs.gov/unnumbered/5230189/report.pdf.]

Robbins, C.S., and Van Velzen, W.T., 1969, The Breeding Bird Survey, 1967 and 1968: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 124, 107 p.

Robbins, C.S., and Van Velzen, W.T., 1974, Progress report on the North American Breeding Bird Survey: Acta Ornithologica, v. 14, no. 8, p. 170–191.

Sauer, J.R., 2008, Rachel Carson's legacy for research and monitoring at the USGS Patuxent Wildlife Research Center: INformation, fall 2008 issue, p. 32–33.

Sauer, J.R., and Geissler, P.H., 1990, Annual indices from route regression analyses, *in* Sauer, J.R., and Droege, Sam, eds., Survey designs and statistical methods for the estimation of avian population trends: Washington, D.C., U.S. Fish and Wildlife Service, Biological Report, v. 90, no. 1, p. 58–62. [Also available at http://digitalmedia.fws.gov/utils/getfile/collection/document/id/1775/filename/1776.pdf.]

Sauer, J.R., Hines, J.E., Fallon, J.E., Pardieck, K.L., Ziolkowski, D.J., Jr., and Link, W.A., 2011, The North American Breeding Bird Survey, Results and analysis 1966–2010 (ver. 12.07.2011): Laurel, MD, U.S. Geological Survey Patuxent Wildlife Research Center, accessed February 16, 2011, at http://www.mbr-pwrc.usgs.gov/bbs/bbs2010.html.

Sauer, J.R., Hines, J.E., Gough, G., Thomas, I., and Peterjohn, B.G., 1997, The North American Breeding Bird Survey results and analysis (ver. 96.4): Laurel, MD, U.S. Geological Survey Patuxent Wildlife Research Center, accessed February 18, 2016, at http://www.mbr-pwrc.usgs.gov/bbs/bbs96.html.

Sauer, J.R., and. Link, W.A., 2011, Analysis of The North American Breeding Bird Survey using hierarchical models: Auk, v. 128, no. 1, p. 87–98. [Also available at http://dx.doi.org/10.1525/auk.2010.09220.]

Sauer, J.R., Link, W.A., Fallon, J.E., Pardieck, K.L., Ziolkowski, D.J., Jr., 2013, The North American Breeding Bird Survey 1966–2011—Summary analysis and species accounts: North American Fauna, v. 79, p. 1–32 plus 2 appendixes, accessed April 1, 2016, at http://dx.doi.org/10.3996/nafa.79.0001.

Sauer, J.R., Link, W.A., Kendall, W.L., and Dolton, D.D., 2010, Comparative analysis of mourning dove population change in North America: Journal of Wildlife Management, v. 74, no. 5, p. 1059–1069. [Also available at http://www.jstor.org/stable/40665180.]

Sauer, J.R., Link, W.A., Kendall, W.L., Kelley, J.R, and Niven, D.K., 2008, A hierarchical model for estimating change in American woodcock populations: Journal of Wildlife Management, v. 72, no. 1, p. 204–214. [Also available at http://dx.doi.org/10.2193/2006-534.]

Sauer, J.R., Pendleton, G.W., and Orsillo, Sandra, 1995, Mapping of bird distributions from point count surveys, *in* Ralph, C.J., Sauer, J.R., and Droege, Sam, eds., Monitoring bird populations by point counts: U.S. Forest Service, Pacific Southwest Research Station, General Technical Report PSW–GTR–149, p. 151–160. [Also available at http://www.fs.fed.us/psw/publications/documents/gtr-149/pg151_160.pdf.]

Sheldon, W.G., 1953, Woodcock studies in Massachusetts: Transactions of the North American Wildlife Conference, v. 18, p. 369–377.

Thogmartin, W.E., Sauer, J.R., and Knutson, M.G., 2004, A hierarchical spatial model of avian abundance with application to cerulean warblers: Ecological Applications, v. 14, no. 6, p. 1766–1779. [Also available at http://dx.doi.org/10.1890/03-5247.]

U.S. Geological Survey, n.d., North American Breeding Bird Survey—Route abundance, trend analysis, and land cover form: U.S. Geological Survey Patuxent Wildlife Research Center, accessed March 25, 2015, at http://www.mbr.pwrc.usgs.gov/bbs/trend/rtehtm13a.nlcd.html.

Veech, J.A., Small, M.F., and Baccus, J.T., 2012, Representativeness of land cover composition along routes of the North American Breeding Bird Survey: Auk, v. 129, no. 2, p. 259–267. [Also available at http://dx.doi.org/10.1525/auk.2012.11242.]

Vogelmann, J.E., Howard, S.M., Yang, Limin, Larson, C.R., Wylie, B.K., and Van Driel, Nick, 2001, Completion of the 1990's national land cover data set for the conterminous United States from landsat thematic mapper data and ancillary data sources: Photogrammetric Engineering and Remote Sensing, v. 67, p. 650–662. [Also available at http://www.mrlc.gov/downloadfile2.php?file=Vogelmann.JE_PERS.67.2001_NLCD1992.pdf.]

Female killdeer guarding eggs at Patuxent Research Refuge, Laurel, MD, 2007. Photo by Matthew C. Perry, U.S. Geological Survey.

The Migratory Bird and Habitat Research Laboratory and the Accelerated Research Program

By Richard A. Coon

The Patuxent Wildlife Research Center (Patuxent) housed two important programs that were not supervised through the office of the Director of Patuxent during the 1960s and 1970s. Although they received administrative support from Patuxent, they were supervised from the U.S. Fish and Wildlife Service (USFWS) headquarters in Washington, D.C. One, the Migratory Bird Populations Station (MBPS), was established in 1961; the other, the Migratory Bird and Habitat Research Laboratory (MBHRL), was established in 1972 (Perry, 2004). This chapter briefly discusses MBPS and how some of its functions were transferred to MBHRL when this new laboratory was created.

Migratory Bird Populations Station

The main purpose of MBPS was to be a central location for the USFWS to study migratory bird population dynamics across political and administrative boundaries. Its responsibilities were international in scope, carried out in cooperation with Canada, Mexico, and the 50 States, as well as universities and private organizations.

Included as part of MBPS was the internationally recognized Bird Banding Laboratory, along with key staff tasked with collecting harvest information, analyzing population and production data, and helping to develop annual hunting regulations for migratory game birds. When the Gabrielson Laboratory was dedicated in 1969 as a major location for USFWS migratory bird programs, all MBPS personnel were moved there, including the Atlantic Flyway Representative position, which had been located in Delaware. The major computer system of the USFWS was then in the Bird Banding Laboratory and functioned to process and analyze the millions of bird banding records to estimate the abundance, survival, and distribution of migratory birds during their annual cycle.

Creation of the Migratory Bird and Habitat Research Laboratory

In July 1972, the management and research functions of MBPS were split and transferred to two newly organized entities. One was the Office of Migratory Bird Management (MBMO), housed at Patuxent but supervised from USFWS headquarters in Washington, D.C. Dr. John P. Rogers was the office's first chief. The other was the newly organized MBHRL at Patuxent, which was added to the Division of Wildlife Research, with Dr. Robert I. Smith as its first director. Dr. Fant W. Martin became director of MBHRL when Smith was called to Washington, D.C., with Jerry Longcore in 1973 to work on the national issue of lead poisoning in waterfowl. Fant's secretary was Marylu Lammers. Fant hired Drs. Franklin Percival and Stanley Anderson to supervise the Game and Non-Game Sections, respectively. Members of the Game Section included Byron (Ken) Williams, Chuck Kimball, Bob Munro, Lois Moyer, Richard Coon, Paul Geisler, George Haas, Jerry Longcore, Jim Nichols, Jim Hines, Tom Dwyer, Matt Perry, Mike Haramis, Holly Obrecht, Fran Uhler, Ralph Andrews, and Frank McGilvrey. Among those involved in nongame work were Chan Robbins, Mark Fuller, Mike Erwin, Deanna Dawson, Barbara Dowell, Elwood Martin, and Marshall Howe.

Migratory Bird Habitat and Research Laboratory Activities

During the 1970s, Patuxent was growing larger. Its staff was concentrating on contaminants research as well as its newest function, the Endangered Species Program, whereas activities such as wetland research (Wetland Ecology Section) were receiving less emphasis. Additionally, Patuxent increased the number of field stations around the country. Because of this shift in emphasis and an expansion of field station responsibilities, the Wetland Ecology Section was transferred to MBHRL.

Shortly after the transfer, the long-running impoundment management program at Patuxent was discontinued.

MBHRL activities in the 1970s were divided between field research and in-house work at Patuxent. One noteworthy feature of work at Patuxent was the increased responsibility for analyzing migratory bird population data. Drs. Dave Anderson and Jim Nichols achieved international prominence with their sophisticated modeling techniques, which improved the management potential for waterfowl populations and other migratory birds on a large scale.

Off-site work on species of concern and species groups was conducted in specific geographic areas. In Maine, Tom Dwyer and Bill Krohn worked on the American woodcock (*Scolopax minor*), and Jerry Longcore focused on the diminishing population status of black ducks (*Anas rubripes*). Matt Perry and Mike Haramis conducted canvasback (*Aythya valisineria*) studies both at Patuxent and on Chesapeake Bay. In South Carolina and Georgia, George Haas conducted extensive research on mourning doves (*Zenaida macroura*). In many of these studies, radiotelemetry techniques were used widely to collect data that otherwise would not have been available.

MBHRL disbanded in 1981, and Patuxent absorbed its functions and responsibilities. Fant Martin had transferred to MBMO in 1980 and, after another year under interim Patuxent Director John Rogers, Jr., the lab was closed as directed by USFWS headquarters.

George Haas, U.S. Fish and Wildlife Service, capturing a dove in South Carolina, 1977. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Accelerated Research Program for Migratory Shore and Upland Game Birds

Since the passage of the Migratory Bird Treaty Act in 1918, the Federal Government and, ultimately, the USFWS, has been responsible for the management and study of migratory birds. One group, generally known as webless migratory birds, had been largely understudied, however. By the mid-1960s, a growing belief existed among wildlife managers that this situation needed to be remedied. Consequently, State wildlife managers working with the USFWS acted to obtain congressional funding for the Accelerated Research Program (ARP), which focused on migratory shore and upland game birds, in 1967 (MacDonald and Evans, 1970).

In 1972, the ARP, under the overall direction of Fant Martin, became one of the programs within MBHRL at Patuxent. The following biologists provided oversight to the program by serving as contract managers: Henry (Milt) Reeves, 1967–68; Duncan MacDonald, 1968–71; Fant Martin, 1971–75; Richard Coon, 1975–80; and Tom Dwyer, 1980–82.

The two primary forces behind the formation of the ARP were the Southeastern Association of Game and Fish Commissioners and the International Association of Game, Fish and Conservation Commissioners (later the International Association of Fish and Wildlife Agencies [IAFWA]). The species to be studied included Wilson's snipe (*Gallinago delicata*), rails (Rallidae), American coots (*Fulica americana*), sandhill cranes (*Grus americana*), American woodcock, and the various doves, principally the mourning dove, and white-winged dove (*Zenaida asiatica*).

The paucity of biological information on these species was reducing the capability of the USFWS and the States to manage them as game birds (for example, setting hunting seasons, determining season length, establishing bag limits).

Young woodcock banded at Patuxent Wildlife Research Center, Laurel, MD, by Brooke Meanley, U.S. Fish and Wildlife Service, 1979. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Frank Percival, U.S. Fish and Wildlife Service, recording data on September dove survey at Patuxent Wildlife Research Center, Laurel, MD, summer 1979. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Their food habits, population status, migration characteristics, and general life histories would be the target of the new research effort. With the loss of habitats for these species increasing, the need for information about the population health, status, and distribution was becoming critical. Techniques such as radiotelemetry, cannon netting, mist netting, night lighting, banding, and color marking were important research tools. In addition to the State wildlife agencies that were seeking funds, many universities and cooperative wildlife units competed for money to support M.S. and Ph.D. studies. After a few years, workshops were held to present, publish, and disseminate tribute research results.

In July 1967, Congress initiated an annual appropriation of $250,000 to fund the ARP. Of this amount, $175,000 was to be contracted to the States to support individual research projects, $50,000 was retained by the USFWS for research on woodcock and mourning doves, and $25,000 was retained for program administration. The USFWS administered the contracts, provided oversight and review for selected projects, and received the final research reports. In the 16 years during which the program was active, 122 research projects were completed in 41 States (Eshmeyer and Harris, 1974).

Research by the USFWS under the ARP was conducted on woodcock in Maine, mainly at the Moosehorn National Wildlife Refuge, first by William Russell and then by William Krohn and Tom Dwyer. In South Carolina and Georgia, Spencer Amend was the first biologist to study mourning doves with ARP funding; he was followed by George Haas.

Termination of the Accelerated Research Program

The ARP was terminated in October 1982, when annual funding was discontinued because of fiscal constraints imposed on the USFWS. Approximately $2.5 million had been awarded to the States over the course of the 16-year program. An estimated 340 publications resulted from the ARP (Ronnie George, Texas Parks and Wildlife Department, written commun., 1985).

An important outgrowth of the ARP was the publication of “Management of Migratory Shore and Upland Game Birds in North America” in 1977, under the direction of the IAFWA (Sanderson, 1977). This book, edited by Glen C. Sanderson of the Illinois Natural History Survey, summarized the data and other information that had been collected to that point, primarily through ARP funding, about migratory shore and upland game birds. Additionally, it identified future actions and needs for these birds, including financial support, to ensure sustainable populations for the public to enjoy. The book was updated and reissued in 1994 (Tacha and Braun, 1994).

Importance of the Accelerated Research Program

A primary value of the ARP was its direct benefit to wildlife managers, particularly at the State level. The vast majority of the studies consisted of applied research that focused on important webless migratory game-bird species. In addition, because proposals for research were guided by the States, the studies were needs based. The ARP arguably enhanced our collective understanding of the biology of webless migratory game birds more than any other wildlife management program. Listed below are a few examples of the many outcomes and benefits that resulted from this important cooperative program:

1. The hunting of mourning doves was legalized in Wyoming, Nebraska, and North Dakota.
2. Hunting pressure and harvest rates were shown to have little adverse effect on mourning dove survival.
3. Hunting seasons on band-tailed pigeons (*Columba fasciata*) were reinstituted in Arizona, Colorado, New Mexico, and Utah.
4. The redefinition of harvest unit boundaries resulted in increased hunting opportunity for snipe and rail hunters.
5. The understanding of the timing of American coot migration was improved.

6. Subpopulations of sandhill cranes were identified.
7. Estimates of allowable harvest rates for sandhill cranes were improved.
8. Identification of woodcock migration routes and wintering locations through intense banding programs allowed for the development of two management units (eastern and western) for improved harvest management.
9. Wetland habitats preferred by rails and common snipe were identified.
10. Census procedures for rails were developed.
11. The interchange of knowledge, thoughts, and ideas among individuals working within the States, the regions, and various other agencies, universities, and organizations was facilitated.

Revitalization of the Accelerated Research Program

Beginning in 1986, there was renewed interest on the part of the States and the USFWS to revitalize the ARP with new funding. After a 9-year delay, $300,000 was made available for the program, which was renamed the Webless Migratory Game Bird Research Program (Dolton, 2002). Funds were set aside by Dr. Ronald Pulliam, then Director of the Biological Resources Division of the U.S. Geological Survey. This one-time funding was followed in 1996 by an annual allocation of $150,000 from the USFWS. Dolton (2002) of the USFWS, Office (now [2016] Division) of Migratory Bird Management, in Denver, CO, reported that in the first 6 years of the renewed program, 32 research projects were completed with more than $1.1 million of program funds. This number increases to approximately $4 million when the contributions of materials, time, and additional support made by State wildlife agencies, universities, and other non-USFWS sources as the research projects were conducted are considered.

Summary

The unique quality of a major wildlife research center like Patuxent is its ability to adapt to changing times, changing research needs, and changing budgets. As managers and directors come and go, new programs are born and older programs disappear. The Migratory Bird and Habitat Research Laboratory (MBHRL) and the Accelerated Research Program (ARP) exemplified changing times and priorities; nevertheless, the achievements of both while they existed left a lasting mark on natural-resource conservation. Since then, Patuxent-wide work has carried on as former MBHRL personnel, including ARP staff, were absorbed into other Patuxent programs. Throughout its history, Patuxent has maintained its reputation as a world-renowned wildlife research center—a tribute to the resiliency and dedication of its staff, whose extraordinary productivity has been sustained throughout.

Normal and albino Virginia rails banded by Mike Haramis at Patuxent River, 1992. Photo by G. Michael Haramis, U.S. Fish and Wildlife Service.

References Cited

Dolton, D.D., 2002, History and administration of the Webless Migratory Game Bird Research Program, 1995–2001: Denver, CO, U.S. Fish and Wildlife Service, Office of Migratory Bird Management, 6 p., accessed March 26, 2015, at http://central.flyways.us/sites/default/files/uploads/Webless_Research_History_0.pdf.

Eschmeyer, P.H., and Harris, V.T., eds., 1974, Bibliography of research publications of the U.S. Bureau of Sport Fisheries and Wildlife, 1928–72: Washington, D.C., Bureau of Sport Fisheries and Wildlife, Resource Publication, no. 120, 154 p.

MacDonald, D.D., and Evans, T.R., 1970, Accelerated research on migratory webless game birds: Washington, D.C., Wildlife Management Institute, Transactions of the North American Wildlife and Natural Resources Conference, v. 35, p. 149–156.

Perry, M.C., 2004, The evolution of Patuxent as a research refuge and a wildlife research center: Laurel, MD, U.S. Geological Survey Patuxent Wildlife Research Center, 20 p., accessed March 27, 2015, at http://www.pwrc.usgs.gov/history/cronhist/PatuxentHistory_Perry.pdf.

Sanderson, G.C., ed., 1977, Management of migratory shore and upland game birds in North America: Washington, D.C., International Association of Fish and Wildlife Agencies, 358 p.

Tacha, T.C., and Braun, C.E., eds., 1994, Migratory shore and upland game bird management: Washington, D.C., International Association of Fish and Wildlife Agencies, 223 p.

Patuxent's American Black Duck Studies from Chesapeake Bay to Maine and Beyond

By Jerry R. Longcore

Introduction

The information in this chapter draws on published literature and unpublished reports written by staff members of the U.S. Geological Survey, Patuxent Wildlife Research Center (Patuxent), during its 75-year history. Reports by Bureau of Biological Survey (Biological Survey) and U.S. Fish and Wildlife Service (USFWS) personnel are included because the research entity currently known as Patuxent was formerly administered by these agencies. Some of the cited reports were prepared by USFWS scientists while they were not working at Patuxent. Literature resulting from work at other Federal and State agencies and private and academic institutions that influenced research at Patuxent on the American black duck (*Anas rubripes*, hereafter referred to as black duck) and that is essential to the discussion of black duck studies is included. Literature citations are selective, but include representative papers that cover four research topics: chemical contaminants, ecology, analyses of banding and survey data and population changes, and the now discredited hypothesis that the mallard (*Anas platyrhynchos*) could competitively exclude black ducks from fertile wetlands.

Captive black ducks at Patuxent Wildlife Research Center, Laurel, MD, March 1992. Photograph by Matthew C. Perry, U.S. Fish and Wildlife Service.

Background

The black duck, a sporting game duck ardently sought throughout its range by waterfowlers, is regaled as "the most sagacious, wary and wildest of all ducks" (Kortright, 1942, p. 164). This species has been a favorite target of coastal gunners along the Atlantic Flyway (Wright, 1947; Sullivan, 2003), inland throughout the Mississippi Flyway (Bellrose and Chase, 1950), and throughout its range in Canada. Regulations governing hunting of waterfowl were historically nearly nonexistent or extremely liberal, with 107-day seasons and large daily bag limits of 75 birds in the 1920s. Shooting was allowed during spring migration, and hunters took sport in seeing how many sitting ducks could be killed with one shot, usually with 8- or 10-gage double-barreled shotguns (Day, 1949, p. 10). Baiting of ducks was allowed (Leopold, 1931), live decoys referred to as "call" ducks (Perry, 1984) were used, and killing of ducks to sell in the markets of large cities occurred with impunity (Buckingham, 1937). The great market hunting areas were along the Atlantic Coast, Lower Mississippi Flyway States, and the Pacific Coast States, especially California (Hornaday, 1913).

Studying the ecology of black ducks and their management was not a research priority during the early years of the Biological Survey, which evolved in 1896 from the Division of Economic Ornithology, formed by an Act of Congress in 1886 and located in the U.S. Department of Agriculture (Perry, 1984). Scientists at that time focused on recording the negative economic effects of avian species on agricultural crops, although they did publish on foods of waterfowl (McAtee, 1913) and bird migration (Cooke, 1906). The Biological Survey, which was in its infancy in 1920 (Hawkins, 1984), started a bird-banding program headed by Frederick C. Lincoln. The Biological Survey was the forerunner of the Bureau of Sport Fisheries and Wildlife, later renamed the U.S. Fish and Wildlife Service and transferred to the Department of the Interior (DOI).

1930s

The Patuxent Research Refuge was established in 1936 by Executive Order 7514 as part of the U.S. Department of Agriculture. In 1939, the Bureau of Fisheries and the Biological Survey were consolidated into one agency and, in 1940, it was transferred to DOI to form the Fish and Wildlife Service (FWS). In 1956, the FWS was divided into the Bureau of Sport Fisheries and Wildlife (BSFW) and the Bureau of Commercial Fisheries, and the FWS became the U.S. Fish and Wildlife Service. In 1970, the Bureau of Commercial Fisheries was transferred back to the Department of Commerce and the BSFW designation was discontinued.

The name "Patuxent Research Refuge" was changed to "Patuxent Wildlife Research Center" in 1956. Scientists during the earliest years of Patuxent Research Refuge pursued work that had been begun in the Biological Survey days, mainly exploring the mystery of bird migration (Cooke, 1915; Lincoln, 1935), that led to the concept of biological flyways of birds as espoused by F.C. Lincoln (Hawkins, 1984), and identifying foods of waterfowl (Cottam, 1939; Martin and Uhler, 1939). During this time, concern for the future of diminishing stocks of waterfowl was acknowledged. Earlier, Cooke (1906, p. 10) had stated, "The principal causes of the diminished numbers of waterfowl have been market hunting, spring shooting, and the destruction of the breeding ground for farming purposes." Waterfowlers on Chesapeake Bay during the "days of plenty" shot from the deadly sinkbox in the 1800s; from 1870 to 1875, it was not uncommon for 15,000 ducks to be killed on Chesapeake Bay in a single day (Sullivan, 2003). A report about gunning on the Eastern Shore of Maryland described the use of corn bait and unplugged guns, the shipping of ducks to markets in Baltimore, and the use of live decoys, but stated that "The activities of the Biological Survey men have been such as to make the natives take precautions" (National Association of Audubon Societies, 1937).

1940s

During the next decade**,** Ira Gabrielson (1947) sounded a call to address the declining black duck population, stating that the "program should be accompanied by restrictions on shooting sufficient to limit kill to less than the annual number of ducks put on the wing." Cottam (1948) addressed the causes of the waterfowl crisis as "destruction of habitat," "subnormal production," and "overshooting." In this period, studies of black ducks by State biologists, especially in Massachusetts, were initiated. Wright (1947, p. 138–139) reported his findings on the black duck in eastern Canada in a progress report to the Chief Naturalist of Ducks Unlimited and concluded the following:

> "The evidence therefore indicates that all is not well with the black duck of the Atlantic Flyway, and that the trouble is probably not to be found in the part of life he spends in reaching the breeding ground and producing the annual crop, but in the gauntlet of gun-fire he faces from southern Canada to the wintering ground and on the wintering ground. The gradual increase in hunting pressure together with the dying off of his favourite winter food, the eelgrass, and the reduction of winter range caused by the steady building up of the human population with its attendant demand for mosquito-free summer cottages along the Atlantic seaboard, has reduced the species to the point where it is impossible, in the east, to find only one duck of any kind in 14 acres of marsh where they were once found in sufficient number that they could be secured with a club."

1950s

During this period, Stewart (1958) published distribution maps for breeding and wintering black duck populations, and Addy (1953) reported on the fall migration of the black duck. In the mid-1950s, the USFWS initiated a series of mid-winter surveys in cooperation with States in the Atlantic and Mississippi Flyways to inventory waterfowl. These mid-winter inventory (MWI) data indicated a total black duck population of 500,000 to 600,000, but this number was declining about 2 percent annually (Serie, 1997, p. 14).

1960s

During the 1960s, an evaluation of the role of chemical contaminants in the decline of the black duck was initiated by analyzing for pesticides in eggs (Reichel and Addy, 1968) and wings (Heath and Prouty, 1967; Heath, 1969). Several contaminants, especially dichlorodiphenyltrichloroethane (DDT) and its metabolites, were detected in eggs and wings, which prompted experimental pen studies in the early 1970s to determine if and how DDT affected reproduction. Stewart (1962) analyzed 1953–59 MWI data and described waterfowl populations, including that of the black duck, in the Upper Chesapeake Bay region. Lucille Stickel edited Stewart's 208-page manuscript, and several Patuxent staff members (Francis M. Uhler, Alexander Martin, Neil Hotchkiss, and Robert Mitchell) assisted in identifying foods of waterfowl sampled in Chesapeake Bay. Chuck Kaczynski and Jake Chamberlain (1968) reported the number of black ducks counted during aerial surveys in eastern Canada. John Sincock (1962) estimated the amounts of food consumed by waterfowl, including the black duck, in Back Bay, Virginia/Currituck Sound, NC.

Atlantic Flyway representatives, who were trained biologists, supported black duck research studies, surveys, and banding projects. In 1967, the Atlantic Flyway Council, Technical Section, created a Black Duck Committee (Serie, 2002); its first action was to organize a Black Duck Symposium in

Chestertown, MD (Barske, 1968). C.E. Addy (1968, p. 2) provided a general review of black duck status at the symposium, which brought together American and Canadian biologists and administrators to review known information about and identify the needs of the black duck. Several Patuxent scientists contributed papers on topics such as harvest and population dynamics (Martinson and others, 1968), aerial surveys (Chamberlain, 1968), environmental pollution (Stickel, 1968), and control of predators and competitors (McGilvrey, 1968). Comments made in the symposium proceedings included, "…it seems obvious that measures need to be taken immediately to bring controllable kill in line with production…" (Wilder, 1968); "We need more quantitative information about non-hunting mortality" (Loughrey, 1968); "Most Canadian biologists are of the opinion that not all available habitat is being used because there are not enough black ducks to occupy it" (Munro, 1968); and "Any rational attempt to reduce the legal take of black ducks should consider the situation in both Canada and the U.S." (Wilder, 1968). At this time, American and Canadian personnel agreed that the harvest of black ducks was affecting the black duck population. This consensus provided a unique opportunity to implement a plan to curtail harvest. This opportunity, however, was not embraced and, in fact, was delayed for years. In addition, Johnsgard (1967) raised the possibility that the black duck (whose gene pool was smaller than that of the mallard) could eventually disappear as a distinct entity through hybridization with the mallard, although such a development was considered unlikely in the near future. This paper and other, similar reports put forward a speculative view that mallards could be the cause of the decline in the number of black ducks. Such speculation may have confounded black duck population studies and fostered controversy that delayed the confirmation of the actual causes of the decline for the next 30 years.

Jerry Longcore, U.S. Fish and Wildlife Service, checking eggs for cracked shells, DDE study, Patuxent Wildlife Research Center, Laurel, MD, spring 1972. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

American black duck female and brood, DDE study, Patuxent Wildlife Research Center, Laurel, MD, spring 1972. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

1970s

This decade brought additional surveys to document concentrations of polychlorinated biphenyl (PCB) and DDT contaminants in black duck eggs (Longcore and Mulhern, 1973) and a survey of lead in wing bones (Stendell and others, 1979). Experimental studies of the effects of dichlorodiphenyldichloroethylene (DDE) on the thickness of black duck egg shells (Longcore and others, 1971) documented extensive shell thinning in the eggs examined compared to those collected in 1968 (Reichel and Addy, 1968). Longcore and Samson (1973) reported a fourfold increase in shell cracking when females were allowed to incubate their own clutches. This finding confirmed that the productivity of some breeding females was decreasing because of the loss of eggs with cracked shells in nests. Negative reproductive effects caused by DDE persisted into the next year, even after the dosage was curtailed (Longcore and Stendell, 1977), adding credence to the hypothesis that chemicals were affecting reproduction. Monitoring of organochlorine residues and mercury in black duck wings continued (Heath and Hill, 1974; White and Heath, 1976; White, 1979), and effects of mercury on black duck survival and reproduction were shown to include reduced egg hatchability and lower duckling survival in captive ducks fed 3 parts per million of methylmercury over 2 years (Finley and Stendell, 1978).

Geis and others (1971) analyzed data from several harvest surveys and concluded that hunting regulations affect hunting mortality rate, which in turn affects the annual survival rate; however, the statistical methods used in this study were later shown to be invalid (Anderson and Burnham, 1976). Because nest loss of ground-nesting black ducks could affect the population, McGilvrey (1971) conditioned black duck females to elevated nest cylinders on a support post equipped with a predator guard. Of 169 captive-reared female black ducks imprinted to these cylinders and then released in the fall, only 39 returned to nest the next spring.

After joining the Patuxent Migratory Bird and Habitat Research Laboratory, which had been established in 1972, Reinecke (1979) reported on the important foods, growth, and development of juvenile Maine black ducks. Hunting mortality typically was considered to be compensatory to other forms of mortality (Nichols and others, 1984), but the concept of a threshold of additivity of hunting losses emerged as Anderson and Burnham (1976, p. 41) stressed that "Whatever this point is, it may be easy to exceed it on the breeding grounds or on areas where the birds may be particularly vulnerable (Jessen, 1970). Harvest rates early in the season on adult females and young on breeding and staging areas could be severe."

In 1976, with an increased commitment to developing an understanding of the variables affecting the black duck, Patuxent sent me to Maine to investigate the breeding ecology of the species. At the same time, Patuxent biologist Dr. Ronald Kirby was assigned to investigate aspects of wintering ecology of black ducks along the Atlantic Coast, focusing on Chesapeake Bay and New Jersey. Implications about the role of the mallard in the black duck population decline persisted as Johnsgard and DiSilvestro (1976) suggested that "….the relatively specialized black duck, through increased competition and hybridization with the much more broadly adaptable mallard, will continue to become an increasingly rarer [sic] component of the North American bird fauna." It seemed to some of us field biologists studying the black duck, however, that "There is always an easy solution for every human problem—neat, plausible and wrong" (Mencken, 1917).

1980s

Black duck conservation and management during this decade benefited from establishment of a Black Duck Committee by the Atlantic Flyway Council, which was chaired by H.E. Howard Spencer, Jr. (Spencer, 1980). This committee compiled a Black Duck Management Plan for North America 1980–2000 with data provided by personnel of Provincial, Federal, and State agencies; organizations; and private citizens. Black duck conservation benefited further from formal establishment of the North American Waterfowl Management Plan (NAWMP) (U.S. Fish and Wildlife Service, 1986) and from increased research, including an array of field studies by several Patuxent scientists. The NAWMP was signed by the governments of the United States and Canada in 1986 (Serie, 1997), and the plan identified the black duck as a "species of international concern." Under the plan, the Black Duck Joint Venture (BDJV) was formed and implemented in 1990 to coordinate data gathering for population surveys, banding, and research. A winter population goal was set at 385,000 black ducks. A technical committee established within the BDJV, composed of American and Canadian biologists, reviewed proposed survey, banding, and research projects, thereby improving the quality of data collected.

Patuxent continued its research on exposure to contaminants and their effects on black ducks. A minute amount (3 parts per million, dry weight) of DDE in the diet of black ducks caused loss of shell thickness and mass (Longcore and Stendell, 1982), but by 1978, the thickness of black duck eggshells had recovered to a pre-1946 mean (Haseltine and others, 1980). This discovery lessened the probability that chemicals were decreasing productivity and contributing to the population decline, but monitoring of organochlorine pesticide residues in black duck wings continued (Cain, 1981; Prouty and Bunck, 1986; Hall and others, 1989). Heinz and Haseltine (1981) documented that chromium added to the diet of young black ducks affected their avoidance behavior; similar effects were determined for cadmium (Heinz and others, 1983). Differential susceptibility to lead poisoning between the black duck and the mallard was suggested as a possible cause of declines in the number of black ducks (Chasko and others, 1984). Rattner and others (1989) refuted the hypothesis that the black duck was more sensitive to lead poisoning than the mallard by documenting the absence of any difference in mortality between these species on the same lead pellet dosage and diet.

The effects of acidic deposition on wetland invertebrates raised concern that growth and survival of black duck ducklings could be negatively affected. The role of wetland acidification on captive black ducks was evaluated at Patuxent with constructed ponds that were experimentally acidified by Haramis and Chu (1987) and Rattner and others (1987), whose findings indicated lower invertebrate food production on acidic ponds and possible adverse effects on ducklings. In subsequent field studies, Longcore and others (2006) reported that black duck broods readily used low-pH wetlands with good survival of ducklings.

Kirby (1988) reviewed enhancement of black duck breeding habitat in the northeastern United States, and Jorde and others (1989) compiled information on existing tidal and nontidal wetlands of the northern Atlantic States. Results of several studies on breeding ecology and survival of black ducks were published by Patuxent scientists and associated students. Longcore and Ringelman (1980) determined variables affecting breeding densities in the Northeast and developed a black duck population model through use of computer simulations (Ringelman and Longcore, 1980). Results of telemetry used on breeding pairs of black ducks in Maine revealed movements and wetland selection by brood-rearing black ducks (Ringelman and Longcore, 1982a), survival of broods to fledging (Ringelman and Longcore, 1982b), habitat types selected and sizes of home ranges of males and females (Ringelman and others, 1982a), nest and brood attentiveness of females (Ringelman and others, 1982b), and survival of females (Ringelman and Longcore, 1983). Krementz and others (1987) determined sources of variation in survival and recovery rates in black ducks, wherein more adults than hatch-year ducks survived and more adult males than adult females survived. Survival rates were similar for young of both genders, but the recovery rate was greater for young males than for young females. Although recovery rates were time dependent, survival rates were not, which indicates that some variations in mortality caused by hunters may be compensated for by

Dan Stotts and Mike Conroy, U.S. Fish and Wildlife Service, recording weight of black ducks, Atlantic City, NJ, 1982. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

other causes. Body mass in winter was not positively related to annual survival (Krementz and others, 1989). In studies of the effects of hunting on black duck survival, Krementz and others (1988) reported that changes in harvest rate under different regulatory schemes resulted in direct effects (that is, an additive effect) on survival of some age or sex classes (such as adult males and juveniles). Rogers and Patterson (1984) reviewed black duck population status and management and noted that average decline in the population was approximately 1.5 percent annually in the 1970s and 1980s.

Grandy (1983) referred to management of the black duck as "a case of 28 years of failure in American wildlife management," and attributed the long-term population decline to excessive harvest of black ducks. Nichols and others (1984) reviewed evidence for compensatory mortality in waterfowl losses, and Anderson and others (1987) advocated the use of experiments to understand black duck population dynamics. Nichols and others (1987) determined that band recovery rates of sympatric black ducks and mallards were similar and results of tests for differences in annual survival rate were equivocal. Conroy and Blandin (1984) identified geographic and temporal differences in band reporting rates for black ducks, but the optimum estimate was a constant 0.43, although this value may overestimate the reporting rate because some reward bands are not reported. Conroy and Krementz (1986) challenged the validity of inferences made by Boyd and Hyslop (1985) regarding effects of hunting on survival rates of black ducks. Conroy and others (1989b) determined mean winter survival rates for female black ducks along the Atlantic Coast as 0.73 for after-hatch-year ducks and 0.60 for hatch-year ducks that had a lower body mass.

Conroy and others (1988) evaluated the aerial transects for the MWI of black ducks and concluded that the survey was a useful index. Diefenbach and others (1988a) identified distributions of wintering populations of black ducks that had a stronger fidelity to coastal wintering sites than inland sites. Young black ducks wintered northeast of young mallards, but no differences in distribution patterns existed between adult birds (Diefenbach and others, 1988b). Longcore and Gibbs (1988) identified critical habitat for black ducks on the Maine coast during the severe winter of 1980–81, when ducks roosted in the lee of islands. Rusch and others (1989) summarized information on the population status and harvest of the black duck. Longcore and others (1987) evaluated black duck-mallard interactions as noted in literature related to Maine and found few records, but numbers of black duck broods were declining substantially statewide on 36 index wetland areas (15,019 acres) in the relative absence of mallard broods (table 1).

Table 1. Numbers of black duck and mallard broods on 36 index wetlands in Maine, 1956–86.

[Modified from Longcore and others, 1987]

Species	Years		
	1956–65	1966–76	1977–86
Black duck	457	328	178
Mallard	2	5	18

Ankney and others (1987) implied that the number of mallards in Ontario and Quebec, Canada, was increasing at the expense of the black duck population, whose numbers were declining in some parts of its range. Data to support this assertion were lacking, however, as noted by Conroy and others (1989a), who commented that no evidence existed for "cause and effect" for the hypothesis of "increasing mallards and decreasing black ducks." Ankney and others (1989) tried to defend their position on the role of the mallard in the black duck decline. The belief that mallards could competitively exclude black ducks from fertile habitats, however, appeared to be losing support.

1990s

The second Black Duck Symposium (Kehoe, 1997) was held at the beginning of this decade. Serie and others (1997) informed on population status and harvest management strategies in the United States, and Serie and Bailey

(1997) discussed implementation of the BDJV. Longcore and Ringelman (1997) reported that, although the area occupied by surface water increased in a 58-square-mile area in south-central Maine, the number of pairs and broods of black ducks decreased from 1958–60 to 1978–80.

In a study of the effect of acid precipitation on the quality of invertebrate food eaten by the black duck, Sparling (1990) evaluated the effects of dietary aluminum, calcium, and phosphorus on the growth and survival of captive black ducks and mallards. Black ducks seemed more sensitive than mallards to treatments low in calcium and phosphorus and high in aluminum. Effects of these diets on bone and liver characteristics of these species were similar (Sparling, 1991). Frazer and others (1990a, 1990b) evaluated home range, movements, and habitat use of post-fledging black ducks in Maine and New Brunswick. Krementz and others (1991) documented historical changes in egg-laying date, clutch size, and nest success of black ducks in Chesapeake Bay and compared the productivity of the black duck to that of the mallard, which was similar (Krementz and others, 1992).

Black duck breeding ranges have been decreasing across the Bird Conservation Regions of Boreal Hardwood Transition and the Great Lakes/St. Lawrence Plain throughout the second half of the 20th century (Pendleton and Sauer, 1992). Krementz and Pendleton (1991) recorded the movements and survival of black duck and mallard ducklings on Chesapeake Bay with implanted transmitters and found no differences in movements between species, but black duck duckling survival rates were greater than mallard survival rates in 1 of 2 years. Longcore and others (1998) determined that mean sizes of Class II-III broods of black ducks (slightly less than 4 to 4.5 ducklings per brood) equaled or exceeded those of mallards regardless of habitat type; moreover, black duck females with broods were not competitively excluded from inhabiting fertile wetlands in Maine. The period (late August to mid-December 1985–87) survival rate for post-fledging female black ducks equipped with transmitters in Maine was 0.593; survival was 0.694 when losses from hunting were censored (Longcore and others, 1991). This period estimate multiplied by interval rates for hunting, winter, and breeding periods produced an annual survival estimate of 0.262, about 12 percent less than the estimate (0.38) made on the basis of analyses of banding data.

Carney (1992) developed keys to identify species of wings submitted during harvest surveys, which facilitated estimating harvest of black ducks by hunters. Conroy and Krementz (1990) reviewed existing evidence that hunting was affecting the black duck population and discussed the biological basis of compensatory as opposed to additive mortality. Blandin (1992) determined population characteristics of black ducks through simulation modeling. Nichols (1991) presented an in-depth review of science, population ecology, and management of black ducks and reported that the statistical methods used in earlier papers had been inappropriate, thereby invalidating their conclusions. Clugston and others (1994) documented the effect of hunter kills related to habitat use for immature female black ducks at Escoumins, Quebec, in 1991. The sample of radiomarked ducks was divided into three groups on the basis of the percentage of times (that is, telemetry locations) recorded in the St. Lawrence Estuary (table 2).

Most hunting took place in the estuary, so most ducks that avoided the estuary survived. These findings support the concept of additivity of hunting losses on breeding and staging areas described by Anderson and Burnham (1976, p. 41), who concluded the "threshold" of additivity of hunting losses "may be easy to exceed on the breeding grounds," whatever that point might be. Kitchens (1994) determined that opening of hunting seasons disrupted use of prime feeding habitats in Missisquoi Bay in Vermont and Quebec, but use resumed when hunting seasons closed. Francis and others (1998) estimated annual survival during three periods on the basis of changes in harvest regulations. Mean survival rate increased from the first (1950–66) to the second (1967–82) period following initial restrictions on harvest, a finding that is consistent with a model of additivity of hunting mortality. The increase in survival rates following a second round of harvest restrictions revealed some evidence for an increase in survival for immature males between the second (1967–82) and third (1983–93) periods. For adults, however, survival increased less than expected if hunting mortality was additive. These researchers concluded that evidence of additive mortality existed in at least some age-sex classes of black ducks in all periods, but that evidence was weaker in the post-1983 period, perhaps indicating that harvest was falling below the threshold for additivity.

Table 2. Mortality of radiomarked black ducks relative to the percentage of times (that is, telemetry locations) that radiomarked ducks were in the Saint Lawrence Estuary.

[Modified from Clugston and others, 1994]

Percentage of telemetry locations recorded in the estuary	Mortality			Total ducks
	Natural	Unknown cause	Shot / probably shot	
Less than 5	2	1	0 / 0	10
35–65	0	1	1 / 0	13
Greater than 95	0	0	10 / 2	15

Sauer and Droege (1997) reported that black ducks were more likely to be declining on Breeding Bird Survey routes on which mallards were observed than on routes without mallards. Krementz and others (1990) responded to criticisms of Dufour and Ankney (1990) about analytical methods used to test for a positive relation between body mass and annual survival of black ducks and determined that the criticisms were unfounded. Merendino and others (1993) speculated that "competitive exclusion" of black ducks from fertile wetlands was the primary cause for the long-term decline of the black duck population in many parts of Ontario. Hoysak and Ankney (1996), however, observing captive ducks, reported that mallards generally were not dominant over black ducks. Later in Maine, McAuley and others (1998) observed aggressive interactions of black ducks and mallards in the field during breeding. They found that male black ducks that instigated an interaction with male mallards did not lose any interactions and displaced mallards 87.2 percent of the time, whereas no change occurred during 12.8 percent of the interactions. In contrast, male mallards that initiated an interaction displaced black ducks during 63.3 percent of the encounters, but were displaced by the black duck during 15.0 percent of the encounters; the remaining 21.7 percent of the encounters resulted in no change. As objective fieldwork replaced conjecture, it became evident that "Science is nothing but organized common sense. The great tragedy of science [is] the slaying of a beautiful hypothesis by an ugly fact…." (Huxley, 1870, p. 6).

2000s

Although Patuxent scientists continued work on various studies during this decade, little attention was focused on contaminants. Field work in Maine (Longcore and others, 2006), however, revealed that low- (< 5.51) pH wetlands, although associated with reduced numbers of acid-intolerant macroinvertebrates, had large numbers of Insecta and supported a greater percentage of broods (78.6 percent), including black duck broods, than wetlands with a pH > 5.51, which supported 21.4 percent of the broods. Longcore and others (2000b) compiled pertinent historical and more recent literature to prepare the Birds of North America series account for the American black duck. Haramis and others (2002, p. 22) evaluated productivity on Smith Island, MD, with radiomarked female black ducks and found that storm tides and predators kept nest success and productivity low.

Earlier, Francis and others (1998) reported that the threshold of additivity for black ducks, especially immature ducks, was exceeded in some years, which supported the caution of Anderson and Burnham (1976) that the "threshold" may be easily exceeded for adult females and young on breeding and staging areas. Therefore, the location and timing of mortality seem to determine whether hunting losses are additive. The time was early in the hunting season, and the location was on the breeding grounds and staging areas. It seems clear, then, how the geographic position of the northern United States and the Canadian provinces with respect to hunting regulations is crucial to the fate of the black duck population. Telemetry data from Nova Scotia, Quebec, and Vermont (Longcore and others, 2000a) further validated the contention of Anderson and Burnham (1976) that harvest on the breeding and staging areas could be severe, as 85 percent of all mortality in those northern study areas was associated with hunting. These data indicate that black ducks that are not shot on breeding and staging areas may have a high survival rate. Survival of immature female black ducks was determined on two adjacent study areas—one in New Brunswick (Parker, 1991), with an early October 1 hunting season opening, and one in Maine (Longcore and others, 1991), with opening delayed until November 15. Kaplan-Meier (Kaplan and Meier, 1958) survival rates for New Brunswick (0.945) and Maine (0.986) were similar in the 1- to 2-month period before hunting began, but declined sharply for marked ducks in New Brunswick when the hunting season opened (table 3).

Most ducks in Maine that were not exposed to hunters in this period did not die. The decrease in survival rate in New Brunswick from 0.945 to 0.348 can be attributed mostly to hunter harvest. The next question, then, was whether black ducks respond if harvest is restricted.

The third Black Duck Symposium was held in 2002 (Perry, 2002). Serie (2002, p. 2) discussed the black duck as a "species of international concern" and noted that the more restrictive harvest regulations beginning in 1984 may have stabilized the MWI for the black duck in the Atlantic Flyway. Another example of a response to harvest restrictions was the stabilization of the results of the breeding black duck survey in Quebec. Even after a sharp decline in numbers (from 27.5 to 16.8 per 100 square kilometers [km^2] [71.2 to 43.5 per 100 square miles (mi^2)]) from 1990 to 1993, where the band recovery rate remained high, the count stabilized from 1994 to 1995 (15.9 to 16.5 per 100 km^2 [41.2 to 42.7 per 100 mi^2] (Dickson, 1995) after retrieved kill declined substantially in Canada.

Table 3. Survival rate of radiomarked hatching-year female black ducks in Maine and New Brunswick, Canada, as a function of waterfowl hunting season opening date.

[Modified from Longcore and others (1991) for Maine and Parker (1991) for New Brunswick, Canada; waterfowl hunting season in New Brunswick, Canada, opened October 1; waterfowl hunting season in Maine opened November 15]

Time interval studied	Location (years studied)	
	Survival rate in Maine (1985–87)	Survival rate in New Brunswick, Canada (1987–88)
Before September 30	0.986	0.945
October 1–15	0.965	0.500
October 16–31	0.885	0.465
November 1–15	0.834	0.348

In Maine, the Department of Inland Fisheries and Wildlife (P.O. Corr, Maine Department of Inland Fisheries and Wildlife, oral commun., 1983) monitored numbers of waterfowl broods, including black ducks, on 34 wetland brood-rearing reference areas. During 1980–83, most duck seasons were 50 days long, with split seasons in the southern hunting zone that opened October 1st in the early or late season. The black duck daily bag limit was either one or two in 3 of 4 years. In following years (1984–88), the season opening was usually delayed in the early split season to about October 15th in the north zone and about November 16th in the south zone. The daily bag limit was either zero or one in all split seasons except 1988, when it reverted to two black ducks per day with no delayed openings in any split season. Numbers of black duck broods on these 34 reference areas by year are shown in figure 1.

Delaying opening date, reducing season length, and reducing daily bag in this northern state positively affected the number of broods counted in years following protection of local breeding pairs. Reed and Boyd (1974) documented the high mortality of local black ducks breeding in the St. Lawrence Estuary during the opening weekend of hunting. Jorde and Stotts (2002, p. 31) dissected the Federal and State MWI data into geographic areas and showed that trends in the number of black ducks varied with geographic region.

Conroy and others (2002) assembled data on an array of variables affecting the black duck population and, with synthetic modeling, evaluated the relative importance of those variables. Longcore (2002, p. 7) contrasted the effects of variables in the summer and winter ranges of black ducks and concluded that the proximate cause of the long-term decline of the black duck population was unlikely to be related to mallard distribution. Link and others (2006) examined black duck Christmas Bird Count (CBC) data on a regional basis and found decreasing populations in the southern and central parts of the wintering range, but more stable populations in the northeastern parts of the range. In addition, the CBC and the MWI showed similar patterns of population change at the scale of the United States, which lends credibility to the long-term MWI data. Zimpfer and Conroy (2006), in their attempt to model production rates in black duck populations, discovered that they could not include habitat variables as predictors and that multicollinearity among some predictors affected results, which indicated that the predictive ability of the models was limited.

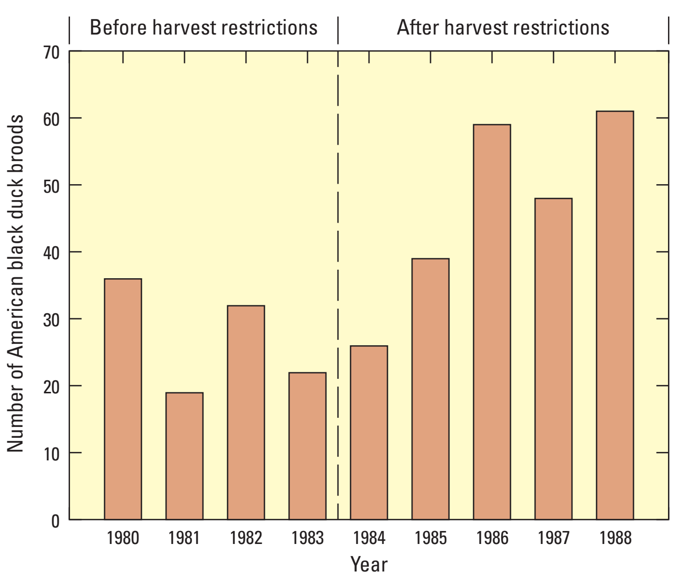


Figure 1. Number of black duck broods on 34 index wetlands in Maine before (1980–83) and after (1984–88) harvest restrictions were applied to protect local breeding pairs. (Data from Maine Department of Inland Fisheries and Wildlife, Bangor, ME)

Kirby and others (2000) published keys of wings to identify mallard, black duck, and hybrids of these species. Petrie and others (2000) found no differences in clutch size, nest success, hen success, duckling survival, or hen survival between black ducks and mallards in New Brunswick, but purported that the difference in population status of the two species was related to differences in breeding propensity arising from competition for breeding resources. In contrast, McAuley and others (2004) documented in nearby Maine that competitive exclusion of black duck pairs from fertile wetlands by mallards was unsupported by field observations, wherein 53 of 65 (81.5 percent) wetlands visited for 2 hours or more were used by both black ducks and mallards. Increasing knowledge of black duck ecology and the positive effects of reduced harvest on the black duck population indicated that "In all science, error precedes the truth, and it is better it should go first than last" (Walpole, 1876, p. 128).

The emerging facts seemed to indicate that hybridization was not a likely cause of the black duck decline (Morton, 1998; Bolen and others, 2002). Furthermore, competitive exclusion was not plausible in light of increasing beaver-created habitat (Longcore and Ringelman, 1980; Seymour and Mitchell, 2006), fewer breeding pairs (Longcore and others, 1987), dynamic use of wetlands by both species (McAuley and others, 2004), the fact that the black duck is as aggressive as the mallard in defending territory and females, and the fact that the black duck is not dominated by the mallard (McAuley and others, 1998). Past studies also determined that black duck brood females are not excluded from fertile wetlands and black duck brood sizes are not different from those of mallards on fertile or infertile wetlands (Longcore and others, 1998), and that mortality of black ducks caused by hunters can be additive to natural mortality (Francis and others, 1998).

So, if not the mallard, what was causing the black duck population to decline? Bolen and others (2002) make a case that sensitivity (that is, wariness or neophobia) of black ducks toward humans may have contributed to the black duck population decline. Without question, the prime Chesapeake Bay wintering area for black ducks has been encroached on by humans around the bay, with a 38-percent increase (from 2.0 to about 2.8 million) in the human population since 1970

(Longcore, 2002). From the 1800s to the 1930s and 1940s, a consensus existed that excessive harvest was the cause of the decline in the black duck population. Even in the late 1960s, biologists and administrators agreed that harvest had to be reduced to stop the decline in black duck numbers (Barske, 1968). The key question was, "What evidence exists to support a conclusion that the black duck population either has, or has not, been affected by harvest regulations?"

Population ecologists typically viewed hunting losses as compensatory—that is, no duck shot in fall or late winter will affect the spring breeding population. In other words, we believed that hunter kill never exceeded a threshold of additivity, whatever that threshold might have been. Francis and others (1998), however, reported that hunter harvest could exceed the threshold and be additive to natural mortality. Because restrictions on the breeding grounds (mostly in Canada) were not effective until about 1990, the reductions in the United States harvest could only stabilize the MWI in the Atlantic Flyway (Serie, 2002, p. 3). Because few black ducks now breed in the United States (as opposed to Canada), a substantial response in population growth probably cannot be expected until the number of breeders that return to the major breeding grounds increases.

Restrictions on harvest in the United States and Canada since 1992 have reversed the downward population trend (Longcore and others, 2000b). Breeding ground pair surveys initiated in the 1990s indicated that as harvest has been reduced (fig. 2), the number of black ducks has increased substantially (fig. 3) while the mallard population also increased substantially (fig. 4).

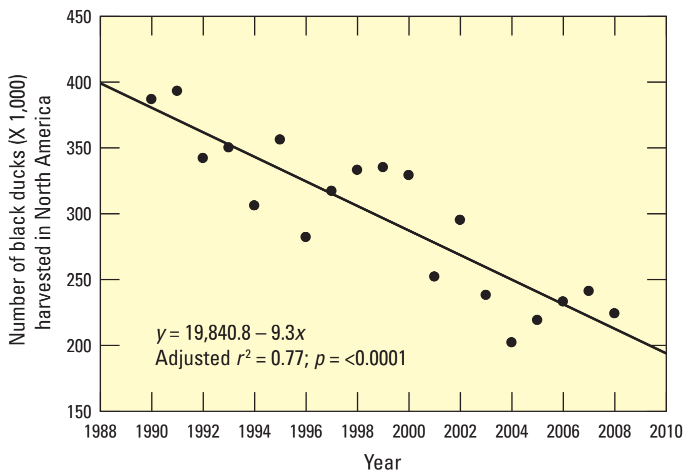


Figure 2. Number of black ducks harvested in North America, 1990–2008. (Data from Office of Migratory Bird Management, U.S. Fish and Wildlife Service, Laurel, MD; <, less than)

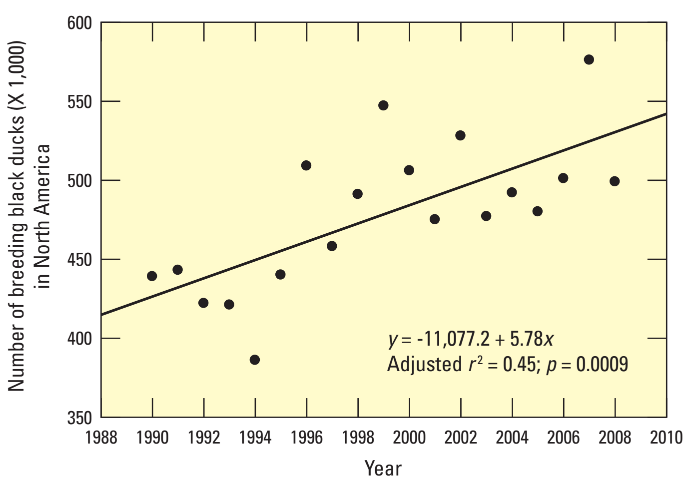


Figure 3. Number of breeding black ducks in North America, 1990–2008. (Data from Office of Migratory Bird Management, U.S. Fish and Wildlife Service, Laurel, MD)

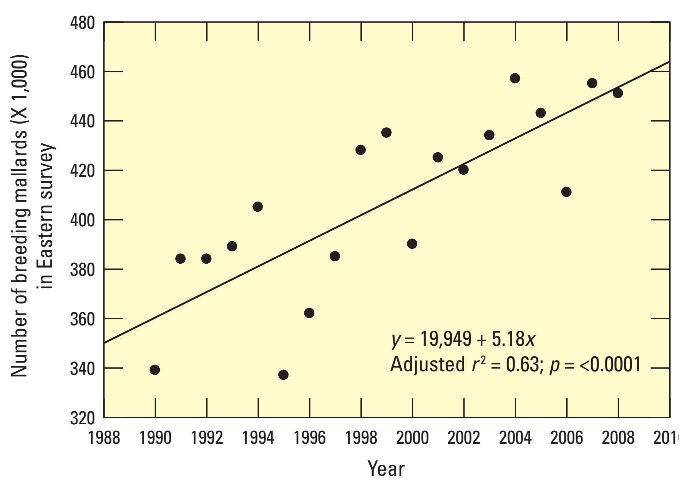


Figure 4. Number of breeding mallards in Eastern Survey, 1990–2008. (Data from Office of Migratory Bird Management, U.S. Fish and Wildlife Service, Laurel, MD; <, less than)

Future Challenges

The original goal of the Black Duck Management Plan for North America, 1980–2000 (Spencer, 1980), was to "…reverse the apparent downward population trend…" as expressed in the MWI. As indicated by data from the improved waterfowl breeding pair survey, that goal has been achieved; however, this success resulted largely from reducing harvest by applying restrictions in areas where opportunity for exceeding the threshold of additivity was small—that is, south of the primary breeding and staging areas. Conjecture about the role of the mallard in the black duck decline was not supported by objective field studies of sympatric populations of these species. Additive effects of hunting were exposed as the black duck population began to recover following substantial reductions in harvest. Even after 80 years of research, an expanding human population, which will increase human disturbance and neophobia (Bolen and others, 2002), and energy development across Canada may affect where black ducks can breed or winter, thereby affecting productivity. For example, some wintering populations of black ducks are shifting northward (Brook and others, 2007), which may affect breeding success or survival, but the outcome is unknown. Over the long term (1955–2007) in Maine, size of waterfowl broods, including those of black ducks, seems to be declining (Schummer and others, 2011); this decline may indicate contaminant effects on egg hatchability or increased duckling mortality. Changes in brood survey methods, however, may have affected these results. For the early brood counts, broods of one or two ducklings were considered "incomplete broods" and were not included in calculating average brood size (H.E. Spencer, Jr., Maine Department of Inland Fisheries and Wildlife, oral commun., 1983), thus biasing the means higher than they would have been if broods of all sizes had been included. The next generation of black duck biologists will undoubtedly be vexed by some of the old issues and faced with new challenges to sustain the North American black duck population.

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References Cited

Addy, C.E., 1953, Fall migration of the black duck: U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 19, 95 p.

Addy, C.E., 1968, General review, *in* Barske, Philip, ed., The black duck—Evaluation, management, and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 2–5.

Anderson, D.R., and Burnham, K.P., 1976, Population ecology of the mallard—VI. The effect of exploitation on survival: Washington, D.C., U.S. Fish and Wildlife Service, Resource Publication 128, 66 p.

Anderson, D.R., Burnham, K.P., Nichols, J.D., and Conroy, M.J., 1987, The need for experiments to understand population dynamics of American black ducks: Wildlife Society Bulletin, v. 15, no. 2, p. 282–284. [Also available at http://www.jstor.org/stable/3782623.]

Ankney, C.D., Dennis, D.G., and Bailey, R.C., 1987, Increasing mallards, decreasing American black ducks—Coincidence or cause and effect?: Journal of Wildlife Management, v. 51, no. 3, p. 523–529. [Also available at http://dx.doi.org/10.2307/3801262.]

Ankney, C.D., Dennis, D.G., and Bailey, R.C., 1989, Increasing mallards, decreasing American black ducks—No evidence for cause and effect—A reply: Journal of Wildlife Management, v. 53, no. 4, p. 1072–1075. [Also available at http://dx.doi.org/10.2307/3809612.]

Barske, Philip, ed., 1968, The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, 193 p.

Bellrose, F.C., and Chase, E.B., 1950, Population losses in the mallard, black duck, and blue-winged teal: Urbana, IL, Illinois Natural History Survey, Biological Notes, no. 22, 27 p. [Also available at http://dx.doi.org/10.5962/bhl.title.15021.]

Blandin, W.W., 1992, Population characteristics and simulation modeling of black ducks: Washington, D.C., U.S. Fish and Wildlife Service, Technical Report Series, no. 11, 200 p. [Also available at http://handle.dtic.mil/100.2/ADA322806.]

Bolen, G.M., Morton, Eugene, Greenberg, Russell, and Derrickson, Scott, 2002, Mallards replacing black ducks—Two views, *in* Perry, M.C., ed., 2002, Black ducks and their Chesapeake Bay habitats—Proceedings of a symposium: U.S. Geological Survey Information and Technical Report USGS/BRD/ITR—2002–0005, p. 16–22. [Also available at https://www.pwrc.usgs.gov/prodabs/perry/6039_perry_searchable.pdf.]

Boyd, H., and Hyslop, C., 1985, Are hunting losses of young black ducks (*Anas rubripes*) too high?, *in* Morgan, B.J.T., and North, P.M., eds., Statistics in ornithology: New York, Springer-Verlag, Lecture Notes in Statistics, v. 29, part C, p. 181–195. [Also available at http://dx.doi.org/10.1007/978-1-4612-5138-5_15.]

Brook, R.W., Ross, R.K., Abraham, K.F., Fronczak, D.L., and Davies, J.C., 2007, Evidence for black duck winter distribution change: Journal of Wildlife Management, v. 73, no. 1, p. 98–103. [Also available at http://dx.doi.org/10.2193/2007-424.]

Buckingham, N., 1937, The Mississippi Valley, *in* Ducks for tomorrow?: New York, National Association of Audubon Societies, p. 10–16.

Cain, B.W., 1981, Nationwide residues of organochlorine compounds in wings of adult mallards and black ducks, 1979–80: Pesticides Monitoring Journal, v. 15, no. 3, p. 128–134. [Also available at http://www.biodiversitylibrary.org/page/26097216.]

Carney, S.M., 1992, Species, age and sex identification of ducks using wing plumage: Washington, D.C., U.S. Fish and Wildlife Service, 144 p. [Also available at http://www4.ncsu.edu/~csdepern/documents/WaterfowlWings.pdf.]

Chamberlain, E.B., 1968, Some observations on aerial surveys of black ducks, *in* Barske, Philip, ed., The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 113–119.

Chasko, G.G., Hoehn, T.R., and Howell-Heller, Penelope, 1984, Toxicity of lead shot to wild black ducks and mallards fed natural foods: Bulletin of Environmental Contamination and Toxicology, v. 32, no. 1 , p. 417–428. [Also available at http://dx.doi.org/10.1007/BF01607518.]

Clugston, D.A., Longcore, J.R., and McAuley, D.G., 1994, Habitat use and movements of postfledging American black ducks (*Anas rubripes*) in the St. Lawrence estuary, Quebec: Canadian Journal of Zoology, v. 72, no. 12, p. 2100–2104. [Also available at http://dx.doi.org/10.1139/z94-281.]

Conroy, M.J., Barnes, G.G., Bethke, R.W., and Nudds, T.D., 1989a, Increasing mallards, decreasing American black ducks—No evidence for cause and effect—A comment: Journal of Wildlife Management, v. 53, no. 4, p. 1065–1071. [Also available at http://dx.doi.org/10.2307/3809611.]

Conroy, M.J., and Blandin, W.W., 1984, Geographic and temporal differences in band reporting rates of American black ducks: Journal of Wildlife Management, v. 48, no. 1, p. 23–36. [Also available at http://dx.doi.org/10.2307/3808450.]

Conroy, M.J., Costanzo, G.R., and Stotts, D.B., 1989b, Winter survival of female American black ducks on the Atlantic coast: Journal of Wildlife Management, v. 53, no. 1, p. 99–109. [Also available at http://dx.doi.org/10.2307/3801314.]

Conroy, M.J., Goldsberry, J.R., Hines, J.E., and Stotts, D.B., 1988, Evaluation of aerial transect surveys for wintering American black ducks: Journal of Wildlife Management, v. 52, no. 4, p. 694–703. [Also available at http://dx.doi.org/10.2307/3800933.]

Conroy, M.J., and Krementz, D.G., 1986, Incorrect inferences regarding the effects of hunting on survival rates of American black ducks: Wildlife Society Bulletin, v. 14, no. 3, p. 326–328. [Also available at http://www.jstor.org/stable/3782257.]

Conroy, M.J., and Krementz, D.G., 1990, A review of the evidence for the effects of hunting on American black duck populations: Transactions North American Wildlife and Natural Resources Conference, v. 55, p. 501–517.

Conroy, M.J., Miller, M.W., and Hines, J.E., 2002, Identification and synthetic modeling of factors affecting American black duck populations: Wildlife Monographs, no. 150, p. 1–64. [Also available at http://www.jstor.org/stable/3830767.]

Cooke, W.W., 1906, Distribution and migration of North American ducks, geese, and swans: Washington, D.C., U.S. Department of Agriculture, Biological Survey, Bulletin no. 26, 90 p. [Also available at http://dx.doi.org/10.5962/bhl.title.56463.]

Cooke, W.W., 1915, Bird migration: Washington, D.C., U.S. Department of Agriculture, Biological Survey, Bulletin no. 185, 47 p.

Cottam, C.M., 1939, Food habits of North American diving ducks: Washington, D.C., U.S. Department of Agriculture, Technical Bulletin no. 643, 140 p. [Also available at http://naldc.nal.usda.gov/download/CAT86200638/PDF.]

Cottam, C.M., 1948, Our waterfowl problem and program—Proceedings of the 1948 Northeastern Game Conference: Boston, MA, Massachusetts Fish and Game Association and Wildlife Management Institute, p. 125–131.

Day, A.M., 1949, North American waterfowl: Harrisburg, PA, Stackpole and Heck, Inc., 329 p.

Dickson, K.M., 1995, Breeding waterfowl survey in eastern Canada and the state of Maine: Ottawa, Ontario, Canada, Canadian Wildlife Service, Progress report (revised August 15, 1995), 11 p.

Diefenbach, D.R., Nichols, J.D., and Hines, J.E., 1988a, Distribution patterns during winter and fidelity to winter areas of American black ducks: Canadian Journal of Zoology, v. 66, no. 7, p. 1506–1513. [Also available at http://dx.doi.org/10.1139/z88-221.]

Diefenbach, D.R., Nichols, J.D., and Hines, J.E., 1988b, Distribution patterns of American black duck and mallard winter band recoveries: Journal of Wildlife Management, v. 52, no. 4, p. 704–710. [Also available at http://dx.doi.org/10.2307/3800934.]

Dufour, K.W., and Ankney, C.D., 1990, Body mass and annual survival in American black ducks—A comment: Ornis Scandinavica, v. 21, no. 4, p. 298–300. [Also available at http://dx.doi.org/10.2307/3676397.]

Finley, M.T., and Stendell, R.C., 1978, Survival and reproductive success of black ducks fed methyl mercury: Environmental Pollution, v. 16, no. 1, p. 51–64. [Also available at http://dx.doi.org/10.1016/0013-9327(78)90137-4.]

Francis, C.M., Sauer, J.R., and Serie, J.R., 1998, Effect of restrictive harvest regulations on survival and recovery rates of American black ducks: Journal of Wildlife Management, v. 62, no. 4, p. 1544–1557. [Also available at http://dx.doi.org/10.2307/3802021.]

Frazer, Catherine, Longcore, J.R., and McAuley, D.G., 1990a, Habitat use by postfledging American black ducks in Maine and New Brunswick: Journal of Wildlife Management, v. 54, no. 3, p. 451–459. [Also available at http://dx.doi.org/10.2307/3809658.]

Frazer, Catherine, Longcore, J.R., and McAuley, D.G., 1990b, Home range and movements of postfledging American black ducks in eastern Maine: Canadian Journal of Zoology, v. 68, no. 6, p. 1288–1291. [Also available at http://dx.doi.org/10.1139/z90-192.]

Geis, A.D., Smith, R.I., and Rogers, J.P., 1971, Black duck distribution, harvest characteristics, and survival: U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 139, 241 p. [Also available at https://babel.hathitrust.org/cgi/pt?id=mdp.39015077581018;view=1up;seq=3.]

Gabrielson, I.N., 1947, A program for the black duck: Harrisburg, PA, Pennsylvania Game Commission, Pennsylvania Game News, v. 17, no. 1, p. 8–9, 31.

Grandy, J.W., 1983, The North American black duck (*Anas rubripes*)—A case study of 28 years of failure in American wildlife management: International Journal for the Study of Animal Problems Supplement, v. 4, no. 4, p. 1–35.

Hall, R.J., Haseltine, S.D., and Geissler, P.H., 1989, Monitoring contaminant exposure—Relative concentrations of organochlorines in three tissues of American black ducks: Environmental Monitoring and Assessment, v. 13, no. 1, p. 11–19. [Also available at http://dx.doi.org/10.1007/BF00398732.]

Haramis, G.M., and Chu, D.S., 1987, Acid rain effects on waterfowl—Use of black duck broods to assess food resources of experimentally acidified wetlands, *in* Diamond, A.W., and Filon, F.L., eds., The value of birds: Cambridge, England, International Council for Bird Preservation, Technical Publication, p. 173–181.

Haramis, G.M., Jorde, D.G., Olsen, G.H., and Stotts, D.B., 2002, Breeding productivity of Smith Island black ducks, *in* Perry, M.C., ed., 2002, Black ducks and their Chesapeake Bay habitats—Proceedings of a symposium: U.S. Geological Survey Information and Technical Report USGS/BRD/ITR—2002–0005, p. 22–30. [Also available at https://www.pwrc.usgs.gov/prodabs/perry/6039_perry_searchable.pdf.]

Haseltine, S.D., Mulhern, B.M., and Stafford, C., 1980, Organochlorine and heavy metal residues in black duck eggs from the Atlantic Flyway, 1978: Pesticides Monitoring Journal, v. 14, no. 2, p. 53–57. [Also available at http://www.biodiversitylibrary.org/item/84301#page/67/mode/1up.]

Hawkins, A.S., 1984, The U.S. response, *in* Hawkins, A.S., Hanson, R.C., Nelson, H.K., and Reeves, H.M., eds., Flyways, pioneering waterfowl management in North America: Washington, D.C., U.S. Fish and Wildlife Service, p. 2–9.

Heath, R.G., 1969, Nationwide residues of organochlorine pesticides in wings of mallards and black ducks: Pesticides Monitoring Journal, v. 3, no. 2, p. 115–123. [Also available at http://www.biodiversitylibrary.org/item/84291#page/127/mode/1up.]

Heath, R.G., and Hill, S.A., 1974, Nationwide organochlorine and mercury residues in wings of adult mallards and black ducks during the 1969–70 hunting season: Pesticide Monitoring Journal, v. 7, nos. 3–4, p. 153–158. [Also available at http://www.biodiversitylibrary.org/page/26095463#page/165/mode/1up.]

Heath, R.G., and Prouty, R.M., 1967, Trial monitoring of pesticides in wings of mallards and black ducks: Bulletin of Environmental Contamination and Toxicology, v. 2, no. 2, p. 101–110. [Also available at http://dx.doi.org/10.1007/BF01684150.]

Heinz, G.H., and Haseltine, S.D., 1981, Avoidance behavior of young black ducks treated with chromium: Toxicology Letters, v. 8, no. 6, p. 307–310. [Also available at http://dx.doi.org/10.1016/0378-4274(81)90118-1.]

Heinz, G.H., Haseltine, S.D., and Sileo, Louis, 1983, Altered avoidance behavior of young black ducks fed cadmium: Environmental Toxicology and Chemistry, v. 2, no. 4, p. 419–421. [Also available at http://dx.doi.org/10.1002/etc.5620020406.]

Hornaday, W.T., 1913, Our vanishing wild life—Its extermination and preservation: New York, Charles Scribner's Sons, 411 p. [Also available at http://www.gutenberg.org/files/13249/13249-h/13249-h.htm.]

Hoysak, D.J., and Ankney, C.D., 1996, Correlates of behavioural dominance in mallards and American black ducks: Animal Behavior, v. 51, no. 2, p. 409–419. [Also available at http://dx.doi.org/10.1006/anbe.1996.0038.]

Huxley, T.H., 1870, Biogensis and abiogenesis—The presidential address to the British Association for the Advancement of Science, *in* Frank, L.R., ed., 1999, Random House Webster's Quotationary: New York, Random House, Inc., 1,039 p.

Jessen, R.L., 1970, Mallard population trends and hunting losses in Minnesota: Journal of Wildlife Management, v. 34, no. 1, p. 93–105. [Also available at http://dx.doi.org/10.2307/3799495.]

Johnsgard, P.A., 1967, Sympatry changes and hybridization incidence in mallards and black ducks: American Midland Naturalist, v. 77, no. 1, p. 51–63. [Available at http://www.jstor.org/stable/2423425.]

Johnsgard, P.A., and DiSilvestro, Rose, 1976, Seventy-five years of changes in mallard-black duck ratios in eastern North America: American Birds, v. 30, no. 5, p. 905–908. [Also available at https://sora.unm.edu/node/112576.]

Jorde, D.G., Longcore, J.R., and Brown, P.W., 1989, Tidal and nontidal wetlands of northern Atlantic states, *in* Smith, L.M., Pederson, R.L., and Kaminski, R.M., eds., Habitat management for migrating and wintering waterfowl in North America: Lubbock, TX, Texas Tech University Press, p. 1–26.

Jorde, D.G., and Stotts, D.B., 2002, The midwinter survey of black ducks, locally and regionally, *in* Perry, M.C., ed., Black ducks and their Chesapeake Bay habitats—Proceedings of a symposium: Reston, VA, U.S. Geological Survey Information and Technical Report USGS/BRD/ITR—2002–0005, p. 31–35. [Also available at https://www.pwrc.usgs.gov/prodabs/perry/6039_perry_searchable.pdf.]

Kaczynski, C.F., and Chamberlain, E.B., 1968, Aerial surveys of Canada geese and black ducks in eastern Canada: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 118, 29 p.

Kaplan, E.L., and Meier, P., 1958, Nonparametric estimation from incomplete observations: Journal of the American Statistical Association, v. 53, no. 282, p. 457–481. [Also available at http://dx.doi.org/10.2307/2281868.]

Kehoe, Pat, comp., ed., 1997, American Black Duck Symposium, Saint John, New Brunswick, Canada, 1990: Black Duck Joint Venture, Grand Falls, New Brunswick, Canada, 57 p.

Kirby, R.E., 1988, American black duck breeding habitat enhancement in the northeastern United States—A review and synthesis: Washington, D.C., U.S. Fish and Wildlife Service, Biological Report, no. 88(4), 50 p. [Also available at http://www.dtic.mil/dtic/tr/fulltext/u2/a322713.pdf.]

Kirby, R.E., Reed, Austin, Dupuis, Pierre, Obrecht, H.H., III, and Quist, W.J., 2000, Description and identification of American black duck, mallard and hybrid wing plumage: U.S. Geological Survey, Biological Resources Division, Special Scientific Report USGS/BRD/BSR—2000–0002, 26 p. [Also available at http://pubs.usgs.gov/bsr/2000/0002/report.pdf.]

Kitchens, C.G., 1994, Variables affecting habitat use and movements of American black ducks and mallards on the Missisquoi National Wildlife Refuge: Orono, ME, University of Maine, M.S. thesis, 73 p.

Kortright, F.H., 1942, The ducks, geese and swans of North America: Washington, D.C., The American Wildlife Institute, 476 p.

Krementz, D.G., Barker, R.J., Link, W.A., Hines, J.E., Corr, P.O., and Owen, R.B., 1990, Response to Dufour and Ankney: Ornis Scandinavica, v. 21, no. 4, p. 301–304. [Also available at http://dx.doi.org/10.2307/3676398.]

Krementz, D.G., Conroy, M.J., Hines, J.E., and Percival, H.F., 1987, Sources of variation in survival and recovery rates of American black ducks: Journal of Wildlife Management, v. 51, no. 4, p. 689–700. [Also available at http://dx.doi.org/10.2307/3801729.]

Krementz, D.G., Conroy, M.J., Hines, J.E., and Percival, H.F., 1988, The effects of hunting on survival rates of American black ducks: Journal of Wildlife Management, v. 52, no. 2, p. 214–226. [Also available at http://dx.doi.org/10.2307/3801225.]

Krementz, D.G., Hines, J.E., Corr, P.O., and Owen, R.B., Jr., 1989, The relationship between body mass and annual survival in American black ducks: Ornis Scandinavica, v. 20, no. 2, p. 81–85. [Also available at http://dx.doi.org/10.2307/3676871.]

Krementz, D.G., and Pendleton, G.W., 1991, Movements and survival of American black duck and mallard broods on Chesapeake Bay: Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies, v. 45, p. 156–166. [Also available at http://www.seafwa.org/html/proceedings/index.php?article=7443.]

Krementz, D.G., Stotts, D.B., Pendleton, G.W., and Hines, J.E., 1992, Comparative productivity of American black ducks and mallards nesting on Chesapeake Bay islands: Canadian Journal of Zoology, v. 70, no. 2, p. 225–228. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z92-035?journalCode=cjz#.Vy6ULEcpRPY.]

Krementz, D.G., Stotts, V.D., Stotts, D.B., Hines J.E., and Funderbunk, S.L., 1991, Historical changes in laying date, clutch size, and nest success of American black ducks: Journal of Wildlife Management, v. 55, no. 3, p. 462–466. [Also available at http://dx.doi.org/10.2307/3808975.]

Leopold, Aldo, 1931, Report on a game survey of the North Central states: Madison, WI, Sporting Arms and Ammunition Manufacturers' Institute, 299 p.

Lincoln, F.C., 1935, The migration of North American birds: Washington, D.C., U.S. Department of Agriculture, Circular no. 363, 72 p. [Also available at https://archive.org/details/migrationofnorth363linc.]

Link, W.A., Sauer, J.R., and Niven, D.K., 2006, A hierarchical model for regional analysis of population change using Christmas Bird Count data, with application to the American black duck: Condor, v. 108, no. 1, p. 13–24. [Also available at http://www.jstor.org/stable/4123193.]

Longcore, J.R., 2002, American black duck summer range versus winter range—A dichotomy of riches, *in* Perry, M.C., ed., 2002, Black ducks and their Chesapeake Bay habitats—Proceedings of a symposium: U.S. Geological Survey Information and Technical Report USGS/BRD/ITR—2002–0005, p. 7–11. [Also available at https://www.pwrc.usgs.gov/prodabs/perry/6039_perry_searchable.pdf.]

Longcore, J.R., Clugston, D.A., and McAuley, D.G., 1998, Brood size of sympatric American black ducks and mallards in Maine: Journal of Wildlife Management, v. 62, no. 1, p. 142–151. [Also available at http://dx.doi.org/10.2307/3802272.]

Longcore, J.R., Corr, P.O., and McAuley, D.G., 1987, Black duck-mallard interactions on breeding areas in Maine: Transactions of the Northeast Section of the Wildlife Society, v. 44, p. 16–32.

Longcore, J.R., and Gibbs, J.P., 1988, Distribution and numbers of American black ducks along the Maine coast during the severe winter of 1980–81, *in* Weller, M.W., ed., Waterfowl in winter: Minneapolis, MN, University of Minnesota Press, p. 377–389.

Longcore, J.R., McAuley, D.G., Clugston, D.A., Bunck, C.M., Giroux, J.F., Ouellet, Clément, Parker, G.R., Dupuis, Pierre, Stotts, D.B., and Goldsberry, J.R., 2000a, Survival of American black ducks radiomarked in Quebec, Nova Scotia, and Vermont: Journal of Wildlife Management, v. 64, no. 1, p. 238–252. [Also available at http://dx.doi.org/10.2307/3802996.]

Longcore, J.R., McAuley, D.G., and Frazer, Catherine, 1991, Survival of postfledging female American black ducks: Journal of Wildlife Management, v. 55, no. 4, p. 573–580. [Also available at http://dx.doi.org/10.2307/3809501.]

Longcore, J.R., McAuley, D.G., Hepp, G.R., and Rhymer, J.M., 2000b, American black duck, *in* Poole, A., and Gill, F., eds., The birds of North America, No. 481: Philadelphia, PA, The Birds of North America, Inc., 36 p. [Also available at http://bna.birds.cornell.edu/bna/species/481/articles/introduction.]

Longcore, J.R., McAuley, D.G., Pendelton, G.W., Bennatti, C.R., Mingo, T.M., and Stromborg, K.L., 2006, Macroinvertebrate abundance, water chemistry, and wetland characteristics affect use of wetlands by avian species in Maine, *in* Hanson, A.R., and Kerekes, J.J., eds., Limnology and aquatic birds: Hydrobiologia, v. 567, p. 143–167. [Also available at http://dx.doi.org/10.1007/978-1-4020-5556-0_12.]

Longcore, J.R., and Mulhern, B.M., 1973, Organochlorine pesticides and polychlorinated biphenyls in black duck eggs from the United States and Canada—1971: Pesticides Monitoring Journal, v. 7, no. 1, p. 62–66. [Also available at http://www.biodiversitylibrary.org/page/26095368.]

Longcore, J.R., and Ringelman, J.K., 1980, Factors affecting waterfowl breeding density and productivity estimates in the Northeast: Transactions of the Northeast Section of the Wildlife Society, Annual Fish and Wildlife Conference, v. 37, p. 169–181.

Longcore, J.R., and Ringelman, J.K., 1997, Densities of breeding American black ducks in southcentral Maine—1958–60 and 1978–80, *in* Kehoe, Pat, comp., ed., American Black Duck Symposium, Saint John, New Brunswick, Canada, 1990: Black Duck Joint Venture, Grand Falls, New Brunswick, Canada, p. 23.

Longcore, J.R., and Samson, F.B., 1973, Eggshell breakage by incubating black ducks fed DDE: Journal of Wildlife Management, v. 37, no. 3, p. 390–394. [Also available at http://dx.doi.org/10.2307/3800130.]

Longcore, J.R., Samson, F.B., and Whittendale, T.W., Jr., 1971, DDE thins eggshells and lowers reproductive success of captive black ducks: Bulletin of Environmental Contamination and Toxicology, v. 6, no. 6, p. 485–490. [Also available at http://dx.doi.org/10.1007/BF01796852.]

Longcore, J.R., and Stendell, R.C., 1977, Shell thinning and reproductive impairment in black ducks after cessation of DDE dosage: Archives of Environmental Contamination and Toxicology, v. 6, no. 1, p. 293–304. [Also available at http://dx.doi.org/10.1007/BF02097770.]

Longcore, J.R., and Stendell, R.C., 1982, Black ducks and DDE—Review and status: Transactions of the Northeast Section of the Wildlife Society, Annual Fish and Wildlife Conference, v. 39, p. 68–75.

Loughrey, A.G., 1968, A Canadian viewpoint, *in* Barske, Philip, ed., The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 171–176.

Martin, A.C., and Uhler, F.M., 1939, Food of game ducks in United States and Canada: Washington, D.C., U.S. Department of Agriculture, Bureau of Biological Survey, Technical Bulletin no. 634, 157 p.

Martinson, R.K., Geis, A.D., and Smith, R.I., 1968, Population dynamics, mortality, survival, production, kill—Black duck harvest and population dynamics in eastern Canada and the Atlantic Flyway, *in* Barske, Philip, ed., The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 21–52.

McAtee, W.L., 1913, Index to papers relating to the food of birds by members of the Biological Survey in publications of the United States Department of Agriculture 1885–1911: Washington, D.C., U.S. Department of Agriculture, Bureau of Biological Survey, Bulletin no. 43, 69 p. [Also available at http://www.biodiversitylibrary.org/item/128010#page/11/mode/1up.]

McAuley, D.G., Clugston, D.A., and Longcore, J.R., 1998, Outcome of aggressive interactions between American black ducks and mallards during the breeding season: Journal of Wildlife Management, v. 62, no. 1, p. 134–141. [Also available at http://dx.doi.org/10.2307/3802271.]

McAuley, D.G., Clugston, D.A., and Longcore, J.R., 2004, Dynamic use of wetlands by black ducks and mallards—Evidence against competitive exclusion: Wildlife Society Bulletin, v. 32, no. 2, p. 465–473. [Also available at http://www.jstor.org/stable/3784986.]

McGilvrey, F.B., 1968, Control of predators and competitors. *in* Barske, Philip, ed., The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 149–154.

McGilvrey, F.B., 1971, Conditioning black ducks to nest in elevated cylinders: Transactions of the Northeast Section of the Wildlife Society, Annual Fish and Wildlife Conference, v. 28, p. 213–220.

Mencken, H.L., 1917, The divine afflatus, New York Evening Mail, November 16, 1917, *in* Platt, Suzy, ed., 1993, Respectfully quoted—A dictionary of quotations: New York, Barnes and Noble, Inc., 520 p.

Merendino, M.T., Ankney, C.D., and Dennis, D.G., 1993, Increasing mallards, decreasing American black ducks—More evidence for cause and effect: Journal of Wildlife Management, v. 57, no. 2, p. 199–208. [Also available at http://dx.doi.org/10.2307/3809414.]

Morton, E.S., 1998, Pairing in mallards and American black ducks—A new view on population decline in American black ducks: Animal Conservation, v. 1, no. 4, p. 239–244. [Also available at http://dx.doi.org/10.1111/j.1469-1795.1998.tb00034.x.]

Munro, W.T., 1968, Historical and current status, Canadian situation, *in* Barske, Philip, ed., The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 6–10.

National Association of Audubon Societies, 1937, Eastern Shore of Maryland, *in* Ducks for tomorrow?: New York, National Association of Audubon Societies, p. 3–7.

Nichols, J.D., 1991, Science, population ecology, and the management of the American black duck: Journal of Wildlife Management, v. 55, no. 4, p. 790–799. [Also available at http://dx.doi.org/10.2307/3809533.]

Nichols, J.D., Conroy, M.J., Anderson, D.R., and Burnham, K.P., 1984, Compensatory mortality in waterfowl populations—A review of the evidence and implications for research and management: Transactions of the North American Wildlife and Natural Resources Conference, v. 49, p. 535–554.

Nichols, J.D., Obrecht, H.H., III, and Hines, J.E., 1987, Survival and band recovery rates of sympatric American black ducks and mallards: Journal of Wildlife Management, v. 51, no. 4, p. 700–710. [Also available at http://dx.doi.org/10.2307/3801730.]

Parker, G.R., 1991, Survival of juvenile American black ducks on a managed wetland in New Brunswick: Journal of Wildlife Management, v. 55, no. 3, p. 467–470. [Also available at http://dx.doi.org/10.2307/3808976.]

Pendleton, G., and Sauer, J.R., 1992, Black duck population units as determined by patterns of band recovery, *in* McCullough, D.R., and Barrett R.H., eds., Wildlife 2001—Populations: New York, Elsevier Applied Science, p. 182–194.

Perry, M.C., 1984, The Patuxent team, *in* Hawkins, A.S., Hanson, R.C., Nelson, H.K., and Reeves, H.M., eds., Flyways, pioneering waterfowl management in North America: Washington, D.C., U.S. Fish and Wildlife Service, p. 113–117.

Perry, M.C., ed., 2002, Black ducks and their Chesapeake Bay habitats—Proceedings of a symposium: U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report USGS/BRD/ITR—2002–0005, 44 p. [Also available at https://www.pwrc.usgs.gov/prodabs/perry/6039_perry_searchable.pdf.]

Petrie, M.J., Drobney, R.D., and Sears, D.T., 2000, Mallard and black duck breeding parameters in New Brunswick—A test of the reproductive rate hypothesis: Journal of Wildlife Management, v. 64, no. 3, p. 832–838. [Also available at http://dx.doi.org/10.2307/3802753.]

Prouty, R.M., and Bunck, C.M., 1986, Organochlorine residues in adult mallards and black duck wings, 1981–1982: Environmental Monitoring and Assessment, v. 6, no. 1, p. 49–57. [Also available at http://dx.doi.org/10.1007/BF00394287.]

Rattner, B.A., Haramis, G.M., Chu, D.S., Bunck, C.M., and Scanes, C.G., 1987, Growth and physiological condition of black ducks reared on acidified wetlands: Canadian Journal of Zoology, v. 65, no. 12, p. 2953–2958. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z87-448#.Vy6aukcpRPZ.]

Rattner, B.A., Fleming, W.J., and Bunck, C.M., 1989, Comparative toxicity of lead shot in black duckss (*Anas rubripes*) and mallards (*Anas platyrhynchos*): Journal of Wildlife Diseases, v. 25, no. 2, p. 175–183. [Also available at http://dx.doi.org/10.7589/0090-3558-25.2.175.]

Reed, A., and Boyd, H., 1974, The impact of opening weekend hunting on local black ducks breeding in the St. Lawrence estuary and on transient ducks, *in* Boyd, H., ed., Canadian Wildlife Service waterfowl studies in eastern Canada, 1969–73: Canadian Wildlife Service Report Series no. 29, p. 84–91.

Reichel, W.L., and Addy, C.E., 1968, A survey of chlorinated pesticide residues in black duck eggs: Bulletin of Environmental Contamination and Toxicology, v. 3, no. 3, p. 174–179. [Also available at http://dx.doi.org/10.1007/BF01684453.]

Reinecke, K.J., 1979, Feeding ecology and development of juvenile black ducks in Maine: Auk, v. 96, no. 4, p. 737–745. [Also available at http://www.jstor.org/stable/4085660.]

Ringelman, J.K., and Longcore, J.R., 1980, Computer simulation models as tools for identifying research needs—A black duck population model: Transactions of the Northeast Section of the Wildlife Society, Annual Fish and Wildlife Conference, v. 37, p. 182–193.

Ringelman, J.K., and Longcore, J.R., 1982a, Movements and wetland selection by brood-rearing black ducks: Journal of Wildlife Management, v. 46, no. 3, p. 615–621. [Also available at http://dx.doi.org/10.2307/3808551.]

Ringelman, J.K., and Longcore, J.R., 1982b, Survival of juvenile black ducks during brood-rearing: Journal of Wildlife Management, v. 46, no. 3, p. 622–628. [Also available at http://dx.doi.org/10.2307/3808552.]

Ringelman, J.K., and Longcore, J.R., 1983, Survival of female black ducks, *Anas rubripes*, during the breeding season: Canadian Field-Naturalist, v. 97, no. 1, p. 62–65. [Also available at http://www.biodiversitylibrary.org/item/89042#9.]

Ringelman, J.K., Longcore, J.R., and Owen, R.B., Jr., 1982a, Breeding habitat selection and home range of radio-marked black ducks (*Anas rubripes*) in Maine: Canadian Journal of Zoology, v. 60, no. 2, p. 241–248.

Ringelman, J.K., Longcore, J.R., and Owen, R.B., Jr., 1982b, Nest and brood attentiveness in female black ducks: Condor, v. 84, no. 1, p. 110–116. [Also available at http://dx.doi.org/10.2307/1367831.]

Rogers, J.P., and Patterson, J.H., 1984, The black duck population and its management: Transactions of the Northeast Section of the Wildlife Society, Annual Fish and Wildlife Conference, v. 49, p. 527–534.

Rusch, D.H., Ankney, C.D., Boyd, H., Longcore, J.R., Montalbano, Frank, III, Ringelman, J.K., and Stotts, V.D., 1989, Population ecology and harvest of the American black duck—A review: Wildlife Society Bulletin, v. 17, no. 4, p. 379–406. [Also available at http://www.jstor.org/stable/3782702.]

Sauer, J.R., and Droege, Sam, 1997, Population trends of black ducks and mallards from the North American Breeding Bird Survey—Are increases in mallards associated with declines in black ducks?, *in* Kehoe, Pat, comp., ed., American Black Duck Symposium, Saint John, New Brunswick, Canada, 1990: Black Duck Joint Venture, Grand Falls, New Brunswick, Canada, p. 25.

Schummer, M.L., Allen, R.B., and Wang, Guiming, 2011, Sizes and long-term trends of duck broods in Maine, 1955–2007: Northeastern Naturalist, v. 18, no. 1, p. 73–86. [Also available at http://dx.doi.org/10.1656/045.018.0107.]

Serie, J.R., 1997, Population status of black ducks and harvest management strategies in the United States, *in* Kehoe, Pat, comp., ed., American Black Duck Symposium, Saint John, New Brunswick, Canada, 1990: Black Duck Joint Venture, Grand Falls, New Brunswick, Canada, p. 12–16.

Serie, J.R., 2002, The American black duck—A species of international concern, *in* Perry, M.C., ed., Black ducks and their Chesapeake Bay habitats—Proceedings of a symposium: U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report USGS/BRD/ITR—2002–0005, p. 2–7. [Also available at https://www.pwrc.usgs.gov/prodabs/perry/6039_perry_searchable.pdf.]

Serie, J.R., and Bailey, B., 1997, Development and implementation of the Black Duck Joint Venture, *in* Kehoe, Pat, comp., ed., American Black Duck Symposium, Saint John, New Brunswick, Canada, 1990: Black Duck Joint Venture, Grand Falls, New Brunswick, Canada, p. 17–19.

Serie, J.R., Trost, R.E., and Sauer, J.R., 1997, Effects of harvest restrictions on black duck harvest and population trends, *in* Kehoe, Pat, comp., ed., American Black Duck Symposium, Saint John, New Brunswick, Canada, 1990: Black Duck Joint Venture, Grand Falls, New Brunswick, Canada, p. 25–26.

Seymour, N.R., and Mitchell, S.C., 2006, American black duck *Anas rubripes* and mallard *A. platyrhynchos* abundance, occurrence of heterospecific pairing and wetland use between 1976 and 2003 in northeastern Nova Scotia, Canada: Wildfowl, v. 56, p. 79–93. [Also available at http://wildfowl.wwt.org.uk/index.php/wildfowl/article/view/1185.]

Sincock, J.L., 1962, Estimating consumption of food by wintering water populations: Charleston, SC, Proceeding of the Sixteenth Annual Conference, Southeastern Association of Game and Fish Commissioners, v. 16, p. 217–221. [Also available at http://www.seafwa.org/html/proceedings/index.php?article=66076.]

Sparling, D.W., 1990, Acid precipitation and food quality—Inhibition of growth and survival in black ducks and mallards by dietary aluminum, calcium, and phosphorus: Archives of Environmental Contamination and Toxicology, v. 19, no. 3, p. 457–463. [Also available at http://dx.doi.org/10.1007/BF01054992.]

Sparling, D.W., 1991, Acid precipitation and food quality—Effects of dietary Al, Ca, and P on bone and liver characteristics in American black duck and mallards: Archives of Environmental Contamination and Toxicology, v. 21, no. 2, p. 281–288. [Also available at http://dx.doi.org/10.1007/BF01055347.]

Spencer, H.E., Jr., comp., 1980, Black duck management plan for North America, 1980–2000: Atlantic Waterfowl Council, v. 1–2, 146 p.

Stendell, R.C., Smith, R.I., Burnham, K.P., and Christensen, R.E., 1979, Exposure of waterfowl to lead—A nationwide survey of residues in wing bones of seven species, 1972–73: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 223, 12 p. [Also available at https://archive.org/details/specialscientifi223unit.]

Stewart, R.E., 1958, Distribution of the black duck: Washington, D.C., U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife, Circular 51, p. 1–8. [Also available at https://babel.hathitrust.org/cgi/pt?id=coo.31924090313754;view=1up;seq=10.]

Stewart, R.E., 1962, Waterfowl populations in the Upper Chesapeake region: Washington, D.C., U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 65, 208 p., 3 maps.

Stickel, L.F., 1968, Environmental pollution, *in* Barske, Philip, ed., 1968, The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 120–125.

Sullivan, C.J., 2003, Waterfowling on the Chesapeake, 1819–1936: Baltimore, MD, Johns Hopkins University Press, 195 p.

U.S. Fish and Wildlife Service, 1986, North American Waterfowl Management Plan: Washington, D.C., U.S. Fish and Wildlife Service, 19 p. [Also available at https://www.fws.gov/migratorybirds/pdf/management/NAWMP/OriginalNAWMP.pdf.]

Walpole, E.H., 1876, *in* Wooléver, Adam, ed., Encyclopædia of quotations—A treasury of wisdom, wit, and humor, odd comparisons and proverbs (6th ed.): Philadelphia, PA, David McKay, 527 p.

White, D.H., 1979, Nationwide residues of organochlorine compounds in wings of adult mallards and black ducks, 1976–77: Pesticides Monitoring Journal, v. 13, no. 1, p. 12–16. [Also available at http://www.biodiversitylibrary.org/page/26111953.]

White, D.H., and Heath, R.G., 1976, Nationwide residues of organochlorines in wings of adult mallards and black ducks, 1972–73: Pesticides Monitoring Journal, v. 9, no. 4, p. 176–185. [Also available at http://www.biodiversitylibrary.org/page/26096040.]

Wilder, N.G., 1968, What comes next? A United States point of view, *in* Barske, Philip, ed., The black duck—Evaluation, management and research—A symposium: Boston, MA, Atlantic Flyway Council and Wildlife Management Institute, p. 168–170.

Wright, B.S., 1947, The black duck in eastern Canada: Fredericton, New Brunswick, Canada, Progress report for June 22, 1945–February 28, 1947 (mimeograph), 151 p.

Zimpfer, N.L., and Conroy, M.J., 2006, Models of production rates in American black duck populations: Journal of Wildlife Management, v. 70, no. 4, p. 947–949. [Also available at http://dx.doi.org/10.2193/0022-541X(2006)70[947:MOPRIA]2.0.CO;2.]

Lucille and Bill Stickel: A Personal Perspective

By Nancy C. Coon

The Early Years

In late 1966, my husband, Richard, and I moved to the Washington, D.C., area, where he had been assigned to the National Naval Medical Center as a Medical Service Corps officer. Thinking that there might be something for me to do on the Washington Mall, I went to the Civil Service Commission and talked to a nice lady named Anna Berozowski. Ms. Berozowski told me that she knew a woman at the Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, who occasionally came down to look through applications. She said she would call to see whether Dr. Lucille Stickel might be interested in talking to me. A few days later, Dr. Stickel did indeed call me, and invited me for a visit. I remember well my tour of Patuxent in the Stickels' Pontiac Tempest convertible. I was hired as a junior biologist working directly with Dr. Stickel. That was the beginning of a 40-year relationship with Dr. Lucille and her husband, Mr. William Stickel. Through the years, I came to know both of them very well. Their profound dedication to their work often made it difficult for others to understand them, particularly Dr. Stickel. She would forever be regarded by some as unapproachable, but by others as compassionate and friendly. She was a pioneer, and a person of immense achievement. When she began her research, it was rare for a woman even to participate in science, much less to triumph to such a degree.

In March 1998, Richard and I had a conversation with Lucille in which she shared with us some details about her early years. She said that her maternal grandfather was a successful lumberman and merchant in Michigan, having emigrated from Canada. He owned land near Alpena, including a lakeside property on which the family had cottages even at that time. Lucille was born in Hillman, MI, in 1915. It was there that her love for all natural things began as she roamed the fields, woods, and lakeside. Lucille's father died during the influenza epidemic that followed World War I, and her mother had a difficult time. Then the Great Depression (hereinafter Depression) came, and the family lost everything.

Lucille was fortunate enough to attend Eastern Michigan University, but worked 30 hours per week while taking a full academic load. After she graduated from college, she taught for 1 year at Ypsilanti, MI. In her view, she did well teaching biology, but she did not enjoy teaching math. She decided that she was not destined to be a teacher and made the decision to return to school at the University of Michigan. She was told that women would have difficulty obtaining jobs and would not be hired before men unless they had top grades, so that was her goal, and she succeeded. Lucille received her master's degree in biology in 1938, and then began working toward her Ph.D. A duplication issue arose when, in her literature review, she came across a paper that essentially reported on her research topic (the embryology of an insect). Consequently, Lucille, not one who was easily discouraged or deterred, began searching for a new research topic.

Lucille and Bill Stickel, Nanjemoy River, MD, 1952. Photo by Francis M. Uhler, Patuxent Research Refuge.

Bill Stickel was born in Terre Haute, IN, in 1912. He attended Indiana State University for 2 years before transferring to the University of Michigan, where he met Lucille. He graduated with Bachelor of Science (1934) and Master of Science (1935) degrees in zoology/botany. He then continued research at the University of Michigan until 1939.

Bill accepted a position as a wildlife biologist with the Civil Service Commission in Washington, D.C., in 1940. He transferred to Patuxent in 1941, and Lucille joined him there. It was at Patuxent that Lucille selected a new research topic, one centered at Patuxent. In 1941, Bill and Lucille were married and thus became lifelong research partners, and stalwart supporters of each other.

Bill and Lucille Stickel on vacation along Steinhatchee River, Taylor County, FL, December 26, 1950. Photo by Francis M. Uhler, Patuxent Research Refuge.

A Beginning at the Patuxent Wildlife Research Center

During the early years at Patuxent, Lucille was offered several positions, including one as an editor, but declined each of them, stating that the men with families recovering from the Depression needed the paying jobs more than she did. In 1943, after spending time as a volunteer, Lucille accepted a position as a junior biologist, beginning a long and illustrious career that helped pave the way not only for women in science, but also for the field of environmental pollution research.

In the early 1940s, Lucille began studying the common box turtle (*Terrapene carolina*) at Patuxent. Perhaps it was only a “folklore story,” but some staff members were told that it was the Stickels’ walks in the Patuxent woods with their dogs and Lucille’s love for mushrooms that caused her to begin recording her observations and, subsequently, marking box turtles. After 1 or 2 years of data collection on box turtles, Lucille sent a partial manuscript to the University of Michigan asking them to consider box turtles as her new research topic. The University of Michigan approved her request, so she continued her box turtle research and received her Ph.D. in 1949. Lucille’s research on box turtle populations at Patuxent spanned several decades, as did her work with her husband, Bill, on black rat snakes (*Elaphe obsoleta obsoleta*). The common box turtle work continues today, and is remarkable as a study of a wildlife species that has continued for decades. In recognition of her pioneering work, the Box Turtle Conservation Workshop Committee established the Lucille F. Stickel Box Turtle Research Award to contribute to the survival of wild box turtle populations.

Dr. Stickel’s interest in plants and animals extended far beyond her well-known research interest in contaminants. She published six papers in the Journal of Mammalogy about populations of small mammals, especially the estimation of home range size. Her scientific work distinguishes her as a member of a small but notable group of women who made important early contributions to the field of mammalogy.

During World War II, Bill was on military furlough from June 1943 to December 1945, serving in the U.S. Army’s 38th Malaria Survey Unit in New Guinea and the Philippines. Not surprisingly, while there, Bill collected reptiles and amphibians, which he donated to the U.S. National Museum. His animal collections included several new species, including one new frog species named for him (*Kaloula conjuncta stickeli*). Lucille told Richard and me that when he returned to the United States, Bill spent some time in a military hospital near Asheville, NC. The hospital stay may have influenced the Stickels’ selection of a retirement home in western North Carolina. Bill returned to Patuxent in 1945 and resumed his research.

The Prime Years at Patuxent

Throughout their long careers, the Stickels dedicated their lives to the field of wildlife toxicology and played a major role in the development of the worldwide recognition of Patuxent as an eminent research institution. They were also deeply interested in its varied habitats, and were often seen on weekends picking up litter and pruning a few trees and shrubs.

From 1952 to 1959, Bill was the editor of "Wildlife Review," which provided professional access to current research developments in the field of wildlife biology. Over the years, he answered many letters of inquiry to Patuxent, providing his unique insights in language that was readily understood. He also gave many tours of Patuxent to visiting dignitaries and the interested public.

Dr. Stickel published her first contaminant paper in 1946, reporting the results of a field study of a mouse population in an area treated with DDT. At that early date, virtually nothing was known about the harmful effects of pesticides on wildlife. Pioneering research by the Stickels and their colleagues formed much of the basis for Rachel Carson's groundbreaking 1962 book, "Silent Spring," which alerted the world to the dangers of pesticides (Carson, 1962).

In the early 1960s, biologists did not know conclusively the cause of population declines in several species of birds that were feeding high on the food chain. Eventually, in 1969, scientists at Patuxent published a paper linking dichlorodiphenyldichloroethylene (DDE), a metabolite of dichlorodiphenyltrichloroethane (DDT), to eggshell thinning in birds, which, in turn, resulted in reduced population recruitment (Heath and others, 1969). The Stickels' concern with the toxic effects of environmental contaminants, especially pesticides and heavy metals, continued throughout their lives. Their research on the use of diagnostic tissue residues of contaminants represents one of the major accomplishments in the history of wildlife toxicology. They demonstrated that the concentrations of pesticides in the brains of dead birds could be used to determine whether those chemicals were responsible for their deaths. With Dr. Stickel's leadership, Patuxent scientists provided the laboratory proof that chemicals were directly related to population declines in many bird populations, including brown pelicans (*Pelecanus occidentalis*) (Blus and others, 1977) and bald eagles (*Haliaeetus leucocephalus*) (Wiemeyer and others, 1993).

In 1968, Dr. Stickel received a Federal Woman of the Year award. She also received the U.S. Department of the Interior Distinguished Service Award. She was the first and only woman to date (2016) who received the Wildlife Society's Aldo Leopold Memorial Award in recognition of her "distinguished service to wildlife conservation," a distinction she received in 1974. Dr. Stickel also was the first woman to direct a major Federal fish and wildlife laboratory, serving as Patuxent's director from 1973 until 1981. Throughout the years, she was recognized as the "first lady" of the U.S. Fish and Wildlife Service, a mantle she wore with humility, but also with grace and charm.

Retirement

The Stickels remained at Patuxent, living in modest government housing, until their retirement, with a combined total of 81 years of government service, in March 1982. They retired to the mountains near Franklin, NC, where they spent many happy years identifying the flora and fauna on their property and the surrounding area, caring for their varied collection of dogs, and supporting local land conservation efforts.

Lucille's interest was in ferns and fungi, two that were difficult to study. Bill collected many plants, worked cooperatively with Western Carolina University in Cullowhee, NC, and added many species to plant distribution records for Macon County, NC, where they lived. Not surprisingly, the Stickels set up a laboratory in the lower level of their home to facilitate their work.

Lucille often inquired about the status of people they had worked with at Patuxent. Bill, on the other hand, did not participate in these discussions and stated that he wished to remember Patuxent and its staff as they were when he and Lucille left. They did not return to Patuxent during retirement.

Bill Stickel died on February 11, 1996, after a lingering illness. For many years, Bill and Lucille had hiked in the mountains on and near their property, drawing detailed maps and observing and recording interesting plants and animals. Lucille continued to hike even when Bill was no longer able to do so, leaving detailed maps of her travels with his caregivers. Eventually Lucille and her dog, Sharlie, moved to a villa in a retirement community in Asheville, NC.

Even after all the intervening years, Dr. Stickel's profound influence on the field of contaminants research remains. The approximately 40 research scientists she hired at Patuxent have published more than 1,000 scientific papers, chaired

Thanksgiving dinner at the Stickels' home at the Patuxent Wildlife Research Center, Laurel, MD, 1951 (from left to right: Bill, Lucille, Clark Webster, Lois Horn, Fran Uhler, and Helen Webster). Photo by Francis M. Uhler, Patuxent Research Refuge.

many symposia, and authored many books in the biological sciences. Several of these scientists have gone on to leadership roles in the U.S. Fish and Wildlife Service, the U.S. Geological Survey, universities, and private industry. As a testament to her continued influence and the respect with which she was regarded, two groups of research scientists she selected, mentored, and inspired visited her at her home in Asheville in late 2006. That 2006 visit was our last visit with her, and she died in Asheville on February 22, 2007 (Coon and Perry, 2007).

Mrs. Lilian Linduska shared some thoughts with me after hearing of Lucille's death. She and her husband, Dr. Joseph Linduska, lived at Patuxent in the 1940s. Lilian's memories are of "a warm and attractive and caring friend. She and Bill loved dogs and always had one or two. She was also a great hostess and party giver. Some of her recipes are still in my files marked with a star indicating they are especially good." I am also fortunate to have some of Lucille Stickel's recipes.

On November 15, 1998, more than 50 years after her first publication on contaminants appeared, the Society of Environmental Toxicology and Chemistry, at its annual meeting in Charlotte, NC, announced that it would present its prestigious Rachel Carson Award to Dr. Lucille F. Stickel. That award is further evidence of the continuing importance of her many contributions to the field of wildlife toxicology.

References Cited

Blus, L.J., Neely, B.S., Jr., Lamont, T.G., and Mulhern, B.M., 1977, Residues of organochlorines and heavy metals in tissues and eggs of brown pelicans, 1969–73: Pesticides Monitoring Journal, v. 11, no. 1, p. 40–53. [Also available at http://www.biodiversitylibrary.org/page/26096344.]

Carson, R.L., 1962, Silent spring: Boston, MA, Houghton Mifflin, 368 p.

Coon, N.C., and Perry, M.C., 2007, Lucille. F. Stickel, 1915–2007: Journal of Wildlife Management, v. 71, no. 8, p. 2827–2828. [Also available at http://dx.doi.org/10.2193/2007-333.]

Heath, R.G., Spann, J.W., and Kreitzer, J.F., 1969, Marked DDE impairment of mallard reproduction in controlled studies: Nature, v. 224, no. 5214, p. 47–48. [Also available at http://dx.doi.org/10.1038/224047a0.]

Wiemeyer, S.N., Bunck, C.M., and Stafford, C.J., 1993, Environmental contaminants in bald eagle eggs—1980–84—and further interpretations of relationships to productivity and shell thickness: Archives of Environmental Contamination and Toxicology, v. 24, no. 2, p. 213–227. [Also available at http://dx.doi.org/10.1007/BF01141351.]

Lucille and Bill Stickel at a picnic table during a farewell party at the Patuxent Wildlife Research Center, Laurel, MD, 1982. Photo by W. James Fleming, U.S. Fish and Wildlife Service.

Lead Poisoning Studies and Shooting Tests with Soft-Iron Shot

By Jerry R. Longcore and Ralph Andrews

Background

Lead poisoning in vertebrates was first reported in Germany in 1842 (von Fuchs, 1842). Waterfowl deaths caused by ingesting toxic lead pellets deposited in wetlands across the United States have been recorded since 1874 (Phillips and Lincoln, 1930). Early reports of lead poisoning in waterfowl were made by Bowles (1908), McAtee (1908), and Wetmore (1919), among others. One proposed remedy was the use of a form of "disintegrable" lead shot—that is, shot made from lead-magnesium alloys (Green and Dowdell, 1936; Dowdell and Green, 1937). Jordan and Bellrose (1950) tested Lubaloy (copper-coated lead) pellets, a lead-tin-phosphorus alloy, a lead-magnesium alloy, and a lead-calcium alloy for toxicity in Pekin ducks, but none of these showed promise under test conditions. Jordan and Bellrose (1950) also tested the components of commercial shot (lead, arsenic, and antimony) and determined that lead was the sole cause of lead poisoning. They tested the effects of the aquatic plant coontail (*Ceratophyllum demersum*) in the diet of lead-dosed ducks and reported a beneficial effect. Elder (1950) measured hunting pressure in waterfowl in Delta Marsh, Manitoba, Canada, with a portable x-ray machine, and noted high percentages (22–49 percent) of juvenile mallard (*Anas platyrhynchos*), Northern pintail (*Anas acuta*), and redhead (*Aythya americana*) ducks with ingested shot.

Bellrose (1959) comprehensively documented the extent of lead-shot pellets deposited by hunters in wetlands across the four flyways and then ingested by waterfowl and found in their gizzards. The Mississippi Flyway Council Planning Committee (1965, unpub. report) brought attention to the unintentional deaths of waterfowl throughout the flyway and advocated action. A year later, Baker (1966) reported on the industrial status of lead shot pellet substitutes that were far from being perfected, and was not optimistic about a substitute, because lead is so well suited for making shot. The continuing decline in duck numbers, however, prompted administrators of the Bureau of Sport Fisheries and Wildlife (part of the U.S. Department of the Interior [DOI]) to join with industry, represented by the Sporting Arms and Ammunition Manufacturers' Institute (SAAMI), to renew efforts to find or develop a nontoxic shot to replace lead shot in waterfowl hunting. In November 1966, SAAMI obtained proposals from three private research firms and then awarded a $100,000, 2-year contract to the Illinois Institute of Technology-Research Institute (IIT-RI) to develop a suitable substitute shot. Research biologists at the Patuxent Wildlife Research Center (Patuxent) evaluated each candidate shot for toxicity to ducks. Through a cooperative agreement (U.S. Department of the Interior, 1966), industry was tasked with testing the shot for ballistics.

Search for Nontoxic Substitute Shot

The challenge for IIT-RI was to find a nontoxic material that was at least as dense as iron (steel), soft enough to avoid scratching or blowing out the choke of shotgun barrels, and available at a reasonable cost (that is, less than two times the price of lead). IIT-RI used three approaches to address this challenge (Andrews and Longcore, 1969). First, researchers would seek to find a biochemical additive, an organic compound with the ability to hinder the formation of soluble lead salts in a duck's gizzard that could be added to powdered lead. This compound would then be extruded in wire form and cold headed (that is, the wire would be altered through force with a series of tools and dies) into shot. A second approach was to develop iron-lead composites in a thermoplastic binder. Low-carbon iron powder would be mixed with lead powder (to increase density), then coated with thermoplastic and extruded in wire form. The third approach was to develop a soft-iron shot by heating the iron to high temperatures to anneal commercial low-carbon steel wire, a process that produces wire that has an extremely coarse grain size and a low carbon content. During the first year of the contract, IIT-RI screened and bench tested many organic compounds and determined that a metallic ion-sequestering compound, ethylenediaminetetraacetic acid (EDTA), and the amino acid creatinine were the most promising. Attempts to extrude powdered lead into wire after the addition of small amounts of these compounds failed because the resulting wire was too brittle for use in fabricating shot. Similarly, the iron-lead thermoplastic mixtures were unsatisfactory because the flow properties of available thermoplastics were inadequate. The possibility of developing a soft-iron shot improved after a commercial low-carbon steel wire that cost only about 10 cents per pound was located. It was believed by the industry that annealing this low-carbon wire in wet hydrogen at 1,600 degrees Fahrenheit would produce a material soft enough for use in fabricating a suitable shot.

Evaluation of Proposed Substitutes at Patuxent Wildlife Research Center

In the summer of 1964, Jerry Longcore was hired as a biological technician in Patuxent's Section of Wetland Ecology to assist Frank McGilvrey in waterfowl studies. Longcore's appointment ended in 1965, but he returned in 1966 at the request of Section Leader John Sincock to assist as a coinvestigator with Ralph Andrews on the lead poisoning project.

Initial testing of potential substitutes for lead shot at Patuxent began in 1965. Locke and others (1966) documented the formation of acid-fast intranuclear inclusion bodies in kidneys of ducks exposed to lead. These inclusion bodies were an accurate marker of lead intoxication in ducks. Irby and others (1967) reported that plastic-coated lead pellets were just as toxic as the lead standard (96 percent mortality); a lead-magnesium alloy was one-half as toxic (54–63 percent mortality); and iron, zinc-coated iron, and copper were slightly toxic (0–12 percent mortality). A second batch of candidate materials (tin-lead alloy, zinc, nickel, Teflon-coated steel, and tin), all in shot form, was used to dose male mallards in a 30-day test (Grandy and others, 1968). The tin-lead alloy caused 27 percent mortality of test mallards; the zinc caused 20 percent mortality. No mortality was observed with nickel, Teflon-coated steel, or pure tin.

Dosing of mallard ducks with proposed substitute shot types followed a standard protocol (Longcore and others, 1974a). Most tests were conducted during 1967–69 in late fall through early spring, when ducks in wetlands in the wild are most typically exposed to spent shot. Replicates (3–5) of a five-duck group were given eight number (no.) 6-size pellets of a proposed substitute shot; and at the same time, replicates were dosed with eight no. 6-size commercial shot as a toxicity standard. For each toxicity test, control mallards (6–16) were maintained. The test diet was whole corn; test duration was 40 days to evaluate shot retention and duck survival. Lead shot coated with nickel to various thicknesses reduced short-term mortality by one-half, but only delayed mortality until the nickel eroded. Combining tin with nickel did not reduce mortality (80 percent) because tin-nickel coating eroded, exposing ducks to lead. Steel shot plated with lead to increase density caused 95 percent mortality, whereas a thinner layer caused 60 percent mortality. Mortality of mallards dosed with two different shot types formed with lead powder and a mucilage type or a polyvinyl acetate water-soluble binder (73 percent) was not different from that of those dosed with the lead-shot test standard (that is, eight no. 6 lead shot) (87 percent). Mortality of mallards dosed with a 1.4-gram (0.05-ounce [oz]) piece of wire containing either 1 or 2 percent creatinine or EDTA ranged from 75 to 90 percent, and was not different from mortality associated with the lead standard (70 percent).

The toxicity test results indicated that if a shot contained lead, the grinding action of the gizzard and acidic gastric juices usually would ultimately expose the lead and result in mortality. In 1933, one of the leading manufacturers of shotgun shells obtained a patent that claimed the addition of only 0.3 to 1.0 percent of phosphor-tin would render lead shot harmless to waterfowl (Jackson, 1933). The patent claimed "…actual experiments with the alloy upon wild ducks have shown it to be harmless." A quantity of this shot was obtained from the company and compared with standard lead shot. All 15 ducks in both groups on a corn diet died, but those dosed with the reputedly nontoxic shot died, on average, 4 days sooner than those dosed with commercial lead shot (Longcore, Andrews, and others, 1974). Finley and Dieter (1978) tested shot formed by combining lead with iron powder, referred to as "sintered" shot, in various amounts. Mortality was greater in ducks dosed with commercial lead shot than in those dosed with the lead-iron shot with a comparable amount of lead. Ingestion of two no. 4 lead-iron shot (0.004 oz of lead) caused slight weight loss and 5 percent mortality, but 45 percent of

Impaction of proventriculus caused by ingested lead shot in the mallard on the left. Photo by Fred B. Samson, Bureau of Sport Fisheries and Wildlife.

ducks dosed with five lead-iron shot died. Other candidate materials were not considered further for reasons of cost, malleability, production limitations, or low density with expected poor ballistics performance.

In addition to proposed substitute shot evaluation, effects of commercial lead shot were tested among adult and juvenile male and female mallards with no difference in mortality (90–100 percent) among sex and age groups. No differences in mortality (93–100 percent) were detected among male and female game-farm mallards, wild mallards, or male American black ducks (*Anas rubripes*). Rattner and others (1989) dosed game-farm mallards, pen-reared black ducks, and wild black ducks with one no. 4 lead shot and fed the ducks pelleted feed. After 14 days, these ducks were redosed with two or four additional no. 4 lead shot. On the basis of all measures of lead toxicity (that is, mortality, weight change, delta-aminolevulinic acid dehydratase activity, and protoporphyrin concentration), black ducks and mallards were considered equally tolerant of lead. Longcore and Andrews (1974) noted, however, that commercial duck pellet feed seems to ameliorate the toxic effects of lead. In contrast, a single no. 4 commercial shot killed 18 to 20 percent of either male or female yearling mallards on a corn diet during a 40-day test (Longcore and others, 1974a). Because Godin (1967) and others reported possible beneficial effects of oyster-shell grit in lead-poisoned ducks, we retested specifically to determine shot retention by fluoroscopy. We raised 50 grit-free mallards by transferring ducklings from brooders to wire-floored pens at 3 weeks of age and never exposed them to grit. Mortality of yearling, lead-dosed (five shot, no. 6 size) mallards offered oyster shell, quartz grit, or no grit was reduced in mallards fed oyster shell (only 4 of 12 died) compared with those on quartz grit (9 of 12 died) or no grit (12 of 12 died). Survival was related to the number of shot retained more than 14 days and to the associated degree of erosion of the shot pellets (Longcore and others, 1974a).

Because foods eaten by ducks may mitigate the effects of ingested lead pellets, Andrews, Longcore, and others initiated a study in January 1967 to clarify earlier work (Jordan, 1952). Jordan and Bellrose (1950) reported that of 80 mallards dosed with five no. 4 or no. 10 lead shot, only 5 ducks died (6.2 percent). We dosed 150 male mallards with either three or eight no. 6 lead shot and held birds on one of five diets—commercial duck pellets, whole corn, cracked corn, mixed small grains, or no food—for 40 days (Ralph Andrews and others, U.S. Fish and Wildlife Service, written commun., 1967). Seventy-five undosed male mallards also were held on the various diets to clarify the effect of diet on shot retention, shot erosion, production of acid-fast intranuclear inclusion bodies in kidneys (Locke and others, 1966), and mortality. We also monitored weight changes related to diet. On each of the grain diets, mortality was 80 percent for those groups of ducks on the eight lead-shot dose, whereas mortality was similar (20–30 percent) for ducks on each of the grain diets and the three lead-shot dose. In contrast, only two ducks on the commercial duck pellet diet and dosed with eight lead shot died, and none of the ducks dosed with three lead shot died. We fluoroscoped surviving ducks on grain diets and determined that they lived because they voided shot before much of the lead could be eroded. Ducks fed commercial duck pellets, however, retained shot as readily as those on the grain diets, and the lead was rapidly eroded in their gizzard, but they did not show signs of poisoning. These data indicate that substances in the duck pellets may combine chemically with lead ions in the digestive tract and protect the ducks from poisoning. A follow-up study documented the efficacy of duck pellets. In late February 1967, each of 50 male mallards was dosed with eight no. 6 lead shot. Twenty were given a diet of whole corn, 10 were given corn meal, 10 were given duck pellets, and 10 were provided with mats of the aquatic vegetation (that is, water-starwort [*Callitriche* sp.]) in their water tanks. After 1 week, 10 of the ducks on whole corn were switched to a diet of duck pellets. Mortality rates recorded were 100 percent on the whole corn diet, 70 percent on the corn-meal diet, 0 percent on duck pellets, 40 percent on corn followed by duck pellets, and 40 percent on the aquatic vegetation. The *Callitriche* did not provide sufficient nutrients; therefore, duck pellets were supplied after 1 week for this group. We concluded that softness of the duck pellets was not the beneficial property and that this aquatic plant did not alleviate poisoning, but that duck pellets lessened the effects of ingesting lead even after signs of lead poisoning were evident. Lead is readily stored in bone and can be detected in many tissues, blood, and organs of organisms exposed to lead. The concentration of lead residues in tissue seems clearly diagnostic of acute lead poisoning in the mallard duck and was determined to equal or exceed 3 parts per million (ppm) in the brain, 6 to 20 ppm in the kidney, 6 to 20 ppm in the liver, and 10 ppm in clotted blood from the heart (Longcore and others, 1974b).

Evaluation of the Killing Efficiency of Lead and Iron Shot

The lack of emergence of any proposed shot type except iron shot as an alternative after all of the testing led to the big question: Does iron shot have adequate ballistics to effectively kill ducks at reasonable distances? Earlier, Bellrose (1959) had tested an annealed iron shot produced by Olin Mathieson Corporation (Clayton, MO) and determined that it performed almost as well as lead shot at distances of as much as 50 yards (yd) (Andrews and Longcore, 1969). The Mississippi Flyway Council Planning Committee (1965, unpub. report) reported on a comparative field test in which no. 2 iron shot killed ducks as effectively as no. 4 lead shot at a range of 40 yd, and resulted in fewer crippled ducks. Several studies documented that when lead shot was used, many ducks were crippled and not brought to bag, and that crippled ducks may recover (Tiemeier, 1941; Trautman, 1943; Whitlock and Miller, 1947; McGinnes and Beck, 1953; Kirby and others, 1981) and may even be harvested later. Bellrose (1953) stated that unretrieved kill was approximately 24 percent of total mallard kill and

Tom Whittendale, Jr., and Jerry Longcore, U.S. Fish and Wildlife Service, weighing a duck used in the lead-shot study, Patuxent Wildlife Research Center, Laurel, MD, 1967. Photo by Fred B. Samson, Bureau of Sport Fisheries and Wildlife.

that only a small percentage of the ducks knocked down, but unretrieved, would actually recover. Because many uncontrolled variables were associated with field tests of shot loads, SAAMI and Patuxent agreed to cooperatively develop a shooting rig that would allow the operators to choose variables independently. The following paragraph from Andrews and Longcore (1969) describes the shooting facility.

> "A unique duck-transport device was engineered by the ammunition industry and constructed at the Patuxent Wildlife Research Center. This automated shooting device moved a tethered, wing-flapping duck across a point where the mounted, pre-aimed gun fired a 'perfect' shot.…A close simulation of a free-flying duck, passing a shooting position, was achieved. The shotgun was mounted on a movable wooden 'horse' and triggered by a solenoid activated through a micro-switch. Other micro-switches braked the carriage on forward and return trips." [A glitch emerged in the braking system as the carriage went over the end of the track. Longcore observed the repeatable malfunction and deduced that the clutch-brake unit required a keyway in the shaft. Industry engineers, although skeptical, agreed to send a new shaft with keyway and key and, once installed, it worked well.] "…A movable control box for the entire facility was positioned beside the gun mount. Sighting stakes were erected for each shooting distance so that the gun could be accurately aimed prior to each shot. Standard 30-inch targets were shot to locate center of patterns and determine positions of sighting stakes. The targets were also used to assure that ducks were centered in the pattern prior to each day of shooting."

Supplies for the test were provided by SAAMI. We used a 12-gage pump shotgun with a full choke and 30-inch (in.) barrel. Because iron shot could potentially affect the choke, which could in turn affect test results, additional barrels were used after a preset number of rounds had been fired through a barrel. The shot types tested were 2.75-in., 1.25-ounce loads of commercial no. 4 lead shot, and no. 6 lead shot as standards for comparison. SAAMI supplied 1,000 pounds of no. 4 soft-iron shot and loaded rounds with slow-burning ball powder for maximum muzzle velocity. The standard iron load was 1 ounce of shot that contained 180 pellets, which was identical to the 180 pellets in a no. 4 lead load. The load of iron shot was encased in a polyethylene liner to further protect gun barrels.

Three thousand game-farm mallards were maintained in fenced impoundments at Patuxent in 1967. Keeping them fed daily was taxing. We received help in maintaining the ducks in

Jerry Longcore and Tom Whittendale, Jr., U.S. Fish and Wildlife Service, readying the target to test the shot pattern in the lead-shot study, Patuxent Wildlife Research Center, Laurel, MD, 1967. Photo by Fred B. Samson, Bureau of Sport Fisheries and Wildlife.

an unexpected way. Serendipitous circumstances led Lorenzo King, a Washington, D.C., taxi driver, to become a biological technician and to participate in the shooting test. One day in Washington, D.C., John Gottschalk, Director of the Bureau of Sport Fisheries and Wildlife, hailed a taxi and was picked up by King. Gottschalk noticed a copy of an outdoor sporting magazine in the back seat of the taxi and questioned King about his interest in the outdoors and wildlife. King indicated that he was very interested, and subsequently applied for and was offered a job in the Section of Wetland Ecology at Patuxent, where he became part of the shooting-test crew.

Robert G. Heath, Patuxent's resident statistician, used a split-plot statistical design to analyze the resulting data. Shooting distance made up whole plots, and combinations of shot type and sex of ducks, arranged factorially, made up subplots. Shot loads were patterned on a 30-in.-diameter circle for each distance before shooting to ensure the gun was centered for a "perfect" shot. For any given combination of shot type and distance, groups of five ducks, either male or female, were shot in random sequence. Shot patterns were obtained after a shooting day to ensure the gun and carriage were performing as required. Initial tests started in March 1968 were at 30, 40, and 50 yd, but because all shot types were effective at 30 yd, we replaced the 30-yd range with a 60-yd range and finished the tests in June 1968. Later, during November–December, we tested the effectiveness of shot loads at 45, 55, and 65 yd. The basic testing was done by firing at the broadside of the passing duck, but 300 additional ducks were shot from a nearly head-on direction at 40 and 50 yd for all shot types. Because of a keen interest in degree of crippling among shot types, we had finite kill categories: "instant kill" (< [less than] 1 minute [min]), "death in 1–5 min," "death within 5 min to 1 day," and "death within 1–10 days." After each day of shooting, all dead ducks were weighed and examined for broken bones before they were stored in a freezer. Live ducks were kept on food and water for 10 days. Throughout most of this work, Tom Whittendale, Jr., was a valuable colleague and provided excellent support as the biological technician on the project. Ducks that were still alive after 10 days were euthanized with carbon monoxide, weighed, and fluoroscoped for embedded shot; a sample of 630 ducks was defeathered to count entrance and exit wounds. This task, like most tasks associated with this study, was somber. Every day, the empathy for the test ducks was etched in the faces of the crew. Although these longevity categories could not translate to field conditions, they were an objective way to compare effectiveness of shot types and inform about potential crippling losses.

The statistical examination of the shooting-test data by analysis of variance did not reveal differences ($P = 0.05$) between no. 4 lead and no. 4 iron shot in numbers of ducks

Tom Whittendale, Jr., and Jerry Longcore, U.S. Fish and Wildlife Service, placing a duck on the transport cart during the lead-shot study at the Patuxent Wildlife Research Center, Laurel, MD, 1967. Photo by Fred B. Samson, Bureau of Sport Fisheries and Wildlife.

Gun firing automatically when the transport cart carrying the duck hits the micro-switch during the lead-shot study at the Patuxent Wildlife Research Center, Laurel, MD, 1967. Photo by Fred B. Samson, Bureau of Sport Fisheries and Wildlife.

"probably bagged" or numbers of "crippled and lost" ducks. No difference in vulnerability was detected between males and females. Shooting distance was the only highly significant ($P = 0.01$) variable related to percentages of ducks "probably bagged." The no. 6 lead load, however, was slightly more effective ($P = 0.05$) than either of the no. 4 loads (180 pellets), most likely because of the greater number of pellets (300) in the no. 6 lead load.

When Winchester-Western decided to conduct its own shooting test in November 1972–March 1973, Dr. Charles Loveless (Assistant Director of Research, U.S. Fish and Wildlife Service [USFWS]) sent Longcore to East Alton, IL, to be the official observer. A duck transport facility, similar to that used at Patuxent but 100 feet long and with more amenities (for example, Plexiglas windows in the shed for the rig operators), had been constructed at Nilo Farms, Brighton, IL. One morning a black limousine arrived at the facility where Ed Kozicky and John Madson (Winchester-Western employees) and Jerry Longcore were preparing to operate the rig. John Olin and Nathaniel Reed (Assistant Secretary of Fish and Wildlife and Parks) emerged from the vehicle and were introduced.

After some explanations, it was time to demonstrate how the facility worked. We caught and tethered a mallard on the carriage; Mr. Kozicky loaded the shotgun and, when all was ready, he hit the switch. As the carriage crossed the firing point, the presighted gun fired and the load of shot killed the duck instantly, revealing the lethality of a nontoxic steel shot that could replace toxic lead. Mr. Olin inquired if the shot was lead shot and Mr. Kozicky replied that it was not; it was steel. Secretary Reed looked at Longcore and nodded, acknowledging the performance of steel shot. Although this was an impressive demonstration of the lethality of iron shot, Winchester-Western interpreted shotshell efficiency to be the ratio of the number of birds bagged to the number crippled (Kozicky and Madson, 1973). All of the ducks (2,400) used in the Nilo Farms test were sent to the University of Wisconsin, Madison, where Cochrane (1976) performed a detailed examination of the carcasses and the shooting-test results. Also, he compared results of the Nilo Farms test with those of Andrews and Longcore (1969) and concluded that the Nilo Farms no. 4 lead shot performed more effectively than the Patuxent no. 4 lead shot or the no. 4 steel shot. This result was not unexpected because of the greater weight and number of pellets in the Nilo Farms no. 4 lead load (that is, 1.5 oz of shot, 2.75-in. Winchester-Western Super-X, XX magnum shell with 198 pellets) compared with the Patuxent no. 4 lead load (that is, 1.25 oz of shot with 180 pellets [10 percent fewer]), which was a less robust load (Kozicky and Madson, 1973). Furthermore, the Nilo Farms no. 4 steel load (that is, 1.13 oz of shot with 214 pellets) was also a superior load compared with the Patuxent no. 4 steel load (that is, 1.0 oz of shot with 180 pellets). In addition, the Nilo Farms no. 4 lead load contained "Grex" (granulated, high-density polyethylene) that filled the interstitial spaces between pellets, thereby helping to maintain pellet sphericity (Lowry, 1973), which improved pattern density (the number of pellets in a 30-in.-diameter circle) from 75 to 88 percent (a 14.8-percent increase) (Cochrane, 1976). The Nilo Farms no. 4 steel load also contained Grex, which resulted in a pattern density of 83 percent, in contrast to a pattern density of 70 percent for the Patuxent no. 4 steel shot load (Kozicky and Madson, 1973). The Nilo Farms no. 4 lead and steel loads were expected to perform better than Patuxent shotshell loads because the Nilo Farms shells had more pellets per load and, therefore, a greater pattern density, and a duck's fate is determined by the number of pellets that strike it (Cochrane, 1976). Criteria used to designate bagged, crippled, and surviving ducks were defined more specifically. Kozicky and Madson (1973) maintained that the only true measure of shotshell efficiency as it relates to field conditions is the ratio of "birds bagged to birds crippled." Despite the greater weight and number of pellets in the no. 4 lead and steel loads used in the Nilo Farms test compared to those used in the Patuxent test, many results were the same—no difference between sex and age groups; in broken bones within the categories of bagged, crippled, and survivor; in capacity to break wing or leg bones; in healing rates of bones; and in mean number of entrance wounds. Numbers of entrance wounds and embedded shot were inversely correlated with distance for all shot types. Crippling rates per 100 mallards for the Nilo Farms no. 4 lead and no. 4 steel loads were inconsistent on the basis of the data of Kozicky and Madson (1973) and depicted in Cochrane (1976, fig. 3). At 50 and 60 yd, the crippling rate of no. 4 steel slightly exceeded that of no. 4 lead, but at 70 and 80 yd, the crippling rate of no. 4 lead substantially exceeded that of no. 4 steel. The anomaly is that at 40 yd, the Nilo Farms no. 4 steel had a crippling rate of approximately 20 percent, whereas the no. 4 lead had a rate of approximately 7 percent as estimated from Cochrane (1976, fig. 3). This anomaly is not fully explained, but Lowry (1973) attributed better performance of no. 4 steel shot in the Patuxent test compared to that of the commercial no. 4 steel shot in the Nilo Farms test to difference in average temperature during shooting—66.5 degrees Fahrenheit (°F) at Patuxent and 36.5 °F at Nilo Farms. At the shooting preserve of the Max McGraw Foundation, Nicklaus (1976) tested no. 4 lead, no. 6 lead, and no. 4 steel on flying mallards released from towers and found no difference in crippling rates between lead and steel. The number of body shot in these flighted ducks did not differ between ducks shot with lead and those shot with steel, and was not statistically different from numbers of embedded shot found in wild populations (Bellrose, 1953).

In an Olin Corporation news item, Madson and Kozicky (n.d.) released the results of the Nilo Farms shooting test of lead and steel shot and attempted to estimate crippling loss for steel shot. They calculated an estimate based on the average annual bag of ducks as 10.6 million during 1955–71 with lead shot; then, if crippling loss is 20 percent, about 2.1 million more ducks are lost as cripples caused by lead shot. Applying the Nilo Farms data to a bag of 10.6 million ducks per season, they estimated the use of iron shot would increase crippling losses by 3 million ducks annually. John P. Rogers (USFWS, Migratory Bird Management Office), however, prepared a dichotomous key of what happened when a duck was fired on and examined 5-min kills for both lead and iron shot used in the Nilo Farms test and in the Patuxent shooting test. His interpretation of the average percentage of ducks not retrieved for all ranges (weighted—that is, 75 percent of all shots 45 yd or fewer) was 2.25 for lead and 6.1 for steel. Therefore, the weighted average was a 16.6-percent increase in unretrieved ducks with steel, resulting in a change from 2.1 million unretrieved ducks to 2.45 million unretrieved ducks—an increase of 350,000 ducks, not 3 million.

With a desire to move forward in implementing a ban on the use of lead shot over wetlands, Robert I. Smith and Longcore were assigned the task of drafting the initial Environmental Impact Statement in 1974 regarding the proposed use of steel shot for hunting waterfowl in the United States (U.S. Fish and Wildlife Service, 1974). The basement of Snowden Hall at Patuxent was the refuge where Longcore spent about 2 months reading documents and drafting sections of the Environmental Impact Statement, which was about 0.5 in. thick. The final Supplemental Environment Impact Statement for Hunting Migratory Birds in the United States increased the thickness of the document to about 2.5 in. by 1986 (U.S. Fish and Wildlife Service, 1986).

The Patuxent shooting tests (Andrews and Longcore, 1969) clearly established the premise that a nontoxic substitute (that is, soft iron, or steel as tagged by its detractors) for lead shot could be developed. The stream of events that followed to implement steel-shot regulations are documented in Friend and others (2009). In 1978, Senator Ted Stevens of Alaska amended the DOI appropriations bill so that the USFWS could not enforce use of nontoxic shot without State approval. In Maine, for example, Longcore was directed to collaborate with the Maine Department of Inland Fisheries and Wildlife to sample duck gizzards and sediments in Merrymeeting Bay to determine whether nontoxic shot was necessary (Longcore and others, 1982). Incidence of ingested lead shot (5.9–8.1 percent) in the gizzards of black ducks from the bay during 1976–80 exceeded the action threshold (5 percent).

Although steel shot was clearly capable of killing ducks, hunters complained about the higher cost of shells and the presumed higher rate of crippling, and their impression was that steel shot was ineffective. It soon became evident that hunters were having difficulty adjusting to the steel shot loads with ballistic characteristics (a smaller, but denser shot pattern; shorter shot string; the need to adjust aiming point as distance increased) different from those of lead shot. Hunters would shoot at a duck, miss the duck, and blame it on the shot load. Poor performance by hunters, in reality, was the result of their inexperience with an unfamiliar product (Tom Roster, Cooperative Nontoxic Shot Education Program, Klamath Falls, OR, oral commun., 1996). Tom Roster, an independent ballistic consultant, author, and mathematician, was also an avid waterfowl hunter who took an interest in the controversy. He conducted many steel-shot shooting clinics, including "participatory" shooting events for hunters; these educational efforts furthered the acceptance by hunters of switching to steel shot or a future nontoxic shot. Necessity was the mother of invention; ammunition manufacturers needed to respond to meet the demand for improved nontoxic shot loads (Taylor, 2011). To evaluate newly developed substitute shot types for toxicity, however, the USFWS needed a protocol to thoroughly test candidate substitutes following standard procedures. This was a timely effort, as the Final Supplemental Environmental Impact Statement for Hunting Migratory Birds was being published in 1986 and steel shot was the only nontoxic shot approved for hunting migratory birds. Ammunition companies, however, were gearing up to seek alternatives to steel shot. In just a few days in 1985, Patuxent scientists Susan D. Haseltine and Barnett A. Rattner (U.S. Fish and Wildlife Service, written commun., 1985) drafted a set of testing protocols for determining toxicity of candidate shot types to waterfowl, which was recast to the format of the Federal Register and published by Morehouse (1986). This early, amended set of protocols appeared annually for about 10 years in the Code of Federal Regulations (Morehouse and Rattner, 1996). As use of other elements and compounds emerged in shot development, Dr. Rattner took the initiative not only to expand the guidelines for testing candidate shot (or coatings) on waterfowl, but to include tests covering effects on other aquatic fauna and flora. This ecosystem-oriented, tiered testing protocol was presented at the Fifteenth Annual Meeting of the Society of Environmental Toxicology and Chemistry (Rattner and Morehouse, 1994). After several lengthy delays, a final rule for the testing protocol was published (Perry and others, 1997). Rattner continued to advise the USFWS on testing guidelines and proposed nontoxic shot for approximately 20 years.

Waterfowl ammunition has evolved with the use of higher velocity steel-shot loads, the development of hexagonal shot for more pellets per payload, and the substitution of loads composed of a blend of steel and tungsten shot, tungsten-iron alloy, tungsten-polymer, tungsten-iron-nickel alloy, and bismuth alloy shot (Sanderson and others, 1997a, 1997b). Implementation of nontoxic shot has progressed from initial regulations on seven National Wildlife Refuges in 1972, to increased regulation in 1985, and to mandatory use of nontoxic shot for waterfowl hunting in the United States in 1991 (Friend and others, 2009). Canada converted to nontoxic shot in 1999 (Taylor, 2011). Longcore recalls that, while expressing concern about how the public would react to the shooting of captive ducks, a high-ranking DOI administrator suggested that the steel shot should have been tested with bags of gelatin. This approach, however, would have been inadequate because of the need to objectively determine the lethality of steel shot and to evaluate its effects on crippling of waterfowl. The emotional effects on the crew of this difficult study were mitigated by the expected conversion to nontoxic shot that ultimately would prevent thousands of migratory waterfowl and scavenging raptors from being poisoned by lead, which causes many birds to starve before dying. Throughout the long process of seeking a nontoxic substitute for lead shot, many State wildlife agencies and nonprofit organizations, especially the National Wildlife Federation, supported Patuxent's efforts and advocated for conversion to nontoxic shot for waterfowl hunting. The ultimate conversion resulted from a broad collaboration of Federal and State agencies, industry, and private citizens, whose persistent efforts greatly reduced the waterfowl lead-poisoning issue.

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Tom Roster, contract ballistics specialist, U.S. Department of the Interior, instructing hunters on techniques for shooting with nontoxic shot, Montana, 1994. Photo by Jeff Herbert, Montana Fish, Wildlife, and Parks Commission.

References Cited

Andrews, Ralph, and Longcore, J.R., 1969, The killing efficiency of soft iron shot: Transactions of the North American Wildlife and Natural Resources Conference, v. 34, p. 337–345.

Baker, J.G., 1966, The industrial status of lead shot substitutes: Transactions of the North American Wildlife and Natural Resources Conference, v. 31, p. 97–103.

Bellrose, F.C., 1953, A preliminary evaluation of cripple losses in waterfowl: Transactions of the North American Wildlife Conference, v. 18, p. 337–360.

Bellrose, F.C., 1959, Lead poisoning as a mortality factor in waterfowl populations: Bulletin of the Illinois Natural History Survey, v. 27, p. 235–288. [Also available at https://www.ideals.illinois.edu/bitstream/handle/2142/44086/Bulletin27%283%29.pdf.]

Bowles, J.H., 1908, Lead poisoning in ducks: Auk, v. 25, no. 3, p. 312–313. [Also available at https://sora.unm.edu/node/8719.]

Cochrane, R.L., 1976, Crippling effects of lead, steel, and copper shot on experimental mallards: Wildlife Monographs, no. 51, p. 7–19. [Also available at http://www.jstor.org/stable/3830469.]

Dowdell, R.L., and Green, R.G., 1937, Lead-magnesium alloys for the prevention of lead poisoning in waterfowl: Mining and Metallurgy, v. 18, p. 463–466.

Elder, W.H., 1950, Measurement of hunting pressure in waterfowl by means of X-ray: Transactions of the North American Wildlife Conference, v. 15, p. 490–504.

Finley, M.T., and Dieter, M.P., 1978, Toxicity of experimental lead-iron shot versus commercial lead shot in mallards: Journal of Wildlife Management, v. 42, no. 1, p. 32–39. [Also available at http://dx.doi.org/10.2307/3800686.]

Friend, Milton, Franson, J.C., and Anderson, W.L., 2009, Biological and societal dimensions of lead poisoning in birds in the USA, *in* Watson, R.T., Fuller, Mark, Pokras, Mark, and Hunt, W.G., eds., Ingestion of lead from spent ammunition—Implications for wildlife and humans: Boise, ID, The Peregrine Fund, p. 34–60. [Also available at http://dx.doi.org/10.4080/ilsa.2009.0104.]

Godin, A.J., 1967, Test of grit types in alleviating lead poisoning in mallards: U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 107, 9 p.

Grandy, J.W., IV, Locke, L.N., and Bagley, G.E., 1968, Relative toxicity of lead and five proposed shot types to pen-reared mallards: Journal of Wildlife Management, v. 32, no. 3, p. 483–488 [Also available at http://dx.doi.org/10.2307/3798926.]

Green, R.G., and Dowdell, R.L., 1936, The prevention of lead poisoning in waterfowl by the use of disintegrable lead shot: Transactions of the North American Wildlife Conference, v. 1, p. 486–489.

Irby, H.D., Locke, L.N., and Bagley, G.E., 1967, Relative toxicity of lead and selected substitute shot types to game-farm mallards: Journal of Wildlife Management, v. 31, no. 2, p. 253–257. [Also available at http://dx.doi.org/10.2307/3798314.]

Jackson, D.D., 1933, Metallic alloy: U.S. Patent no. US1900182, 2 p. [Also available at http://www.freepatentsonline.com/1900182.pdf.]

Jordan, J.S., 1952, Lead poisoning in migratory waterfowl, with special reference to the mallard, *Anas platyrhynchos L.*: Ann Arbor, MI, University of Michigan, Ph.D. dissertation, 144 p.

Jordan, J.S., and Bellrose, F.C., 1950, Shot alloys and lead poisoning in waterfowl: Transactions of the North American Wildlife Conference, v. 15, p. 155–170.

Kirby, R.E., Riechman, J.H., and Schoenfelder, T.W., 1981, Recuperation from crippling in ducks: Wildlife Society Bulletin, v. 9, no. 2, p. 150–153. [Also available at http://www.jstor.org/stable/3781586.]

Kozicky, E., and Madson, J., 1973, Nilo shotshell efficiency test on experimental mallard ducks, 1972–73: Proceedings of the International Association of Game, Fish and Conservation Commissioners, v. 63, p. 100–117.

Locke, L.N., Bagley, G.E., and Irby, H.D., 1966, Acid-fast intranuclear inclusion bodies in the kidneys of mallards fed lead shot: Journal of Wildlife Diseases, v. 2, no. 4, p. 127–131. [Also available at http://dx.doi.org/10.7589/0090-3558-2.4.127.]

Longcore, J.R., Andrews, Ralph, Locke, L.N., Bagley, G.E., and Young, L.T., 1974a, Toxicity of lead and proposed substitute shot to mallards: U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 183, 23 p. [Also available at https://archive.org/details/toxicityofleadpr00long.]

Longcore, J.R., Corr, P.O., and Spencer, H.E. Jr., 1982, Lead shot incidence in sediments and waterfowl gizzards from Merrymeeting Bay, Maine: Wildlife Society Bulletin, v. 10, no. 1, p. 3–10. [Also available at http://www.jstor.org/stable/3781795.]

Longcore, J.R., Locke, L.N., Bagley, G.E., and Andrews, Ralph, 1974b, Significance of lead residues in mallard tissues: U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 182, 24 p. [Also available at https://archive.org/details/significanceofle00long.]

Lowry, E.B., 1973, The Nilo lethality model: Proceedings of the International Association of Game, Fish and Conservation Commissioners, v. 63, p. 117–141.

Madson, J., and Kozicky, E., [n.d.], The Nilo shotshell efficiency study: New Haven, CT, Olin Corporation, Winchester-Western Division, 6 p. plus appendix.

McAtee, W.L., 1908, Lead poisoning in ducks: Auk, v. 25, p. 472. [Also available at https://sora.unm.edu/node/8772.]

McGinnes, B.S., and Beck, R.A., 1953, Recuperative rate of a wing-shot mallard: Journal of Wildlife Management, v. 17, no. 4, p. 541–542. [Also available at http://dx.doi.org/10.2307/3797072.]

Morehouse, K.A., 1986, Migratory bird hunting—Nontoxic shot approval procedures: Federal Register, v. 51, no. 225, p. 42098–42107.

Morehouse, K.A., and Rattner, B.A., 1996, Migratory bird hunting—Amended test protocol for nontoxic shot approval procedures for shot and shot coatings: Federal Register, v. 61, no. 18, p. 2470–2477. [Also available at https://www.gpo.gov/fdsys/pkg/FR-1996-01-26/pdf/96-1179.pdf.]

Nicklaus, R.H., 1976, Effects of lead and steel shot on shooting of flighted mallards: Wildlife Monographs, no. 51, p. 21–29. [Also available at http://www.jstor.org/stable/3830470.]

Perry, C.M., Morehouse, K.A., and Rattner, B.A., 1997, Migratory bird hunting—Revised test protocol for nontoxic approval procedures for shot and shot coatings—Final rule: Federal Register, v. 62, no. 230, p. 63608–63615. [Also available at https://www.gpo.gov/fdsys/pkg/FR-1997-12-01/pdf/97-31328.pdf.]

Phillips, J.C., and Lincoln, F.C., 1930, American waterfowl—Their present situation and the outlook for their future: Boston and New York, Houghton Mifflin Company, 312 p.

Rattner, B.A., Fleming, W.J., and Bunck, C.M., 1989, Comparative toxicity of lead shot in black ducks (*Anas rubripes*) and mallards (*Anas platyrhynchos*): Journal of Wildlife Diseases, v. 25, no. 2, p. 175–183. [Also available at http://dx.doi.org/10.7589/0090-3558-25.2.175.]

Rattner, B.A., and Morehouse, K.A., 1994, Ecological tiered testing protocol proposed for registration of shot used to hunt waterfowl: Proceedings of the 15th Annual Meeting of the Society of Environmental Toxicology and Chemistry, annual meeting abstract book, v. 15, abstract no. 90.

Sanderson, G.C., Anderson, W.L., Foley, G.L., Duncan, K.L., Skowron, L.M., Brawn, J.D., and Seets, J.W., 1997a, Toxicity of ingested bismuth alloy shot in game-farm mallards—Chronic health effects and effects on reproduction: Champaign, IL, Illinois Natural History Survey Bulletin, v. 35, no. 4, p. 216–252. [Also available at https://www.ideals.illinois.edu/handle/2142/26524.]

Sanderson, G.C., Anderson, W.L., Foley, G.L., Skowron, L.M., Brawn, J.D., and Seets, J.W., 1997b, Toxicity of ingested bismuth alloy shot in game-farm mallards: Champaign, IL, Illinois Natural History Survey Bulletin, v. 35, no. 3, p. 183–215. [Also available at https://www.ideals.illinois.edu/bitstream/handle/2142/26522/Bulletin35(3).pdf.]

Taylor, J., 2011, The evolution of steel shot—Modern waterfowl ammunition packs a lethal punch: Delta Waterfowl, v. 7, p. 28–29.

Tiemeier, O.W., 1941, Repaired bone injuries in birds: Auk, v. 58, p. 350–359. [Also available at https://sora.unm.edu/node/18203.]

Trautman, M.B., 1943, Normal flight of a black duck after healing of wing fractures: Wilson Bulletin, v. 55, no. 2, p. 126. [Also available at https://sora.unm.edu/node/126481.]

U.S. Department of the Interior, 1966, Arms industry sponsors research program to eliminate waterfowl losses from lead poisoning: News release, December 15, 1966, p. 1.

U.S. Fish and Wildlife Service, 1974, Proposed use of steel shot for hunting waterfowl in the United States—Draft Environmental Statement DES 7–76: Washington, D.C., U.S. Department of the Interior, 79 p.

U.S. Fish and Wildlife Service, 1986, Final supplemental environmental impact statement—Use of steel shot for hunting migratory birds in the United States: Washington, D.C., U.S. Department of the Interior, 558 p.

von Fuchs, C.J., 1842, Die schädlichen einflüsse der bleibergwerke auf die gesundheit der hausthiere, insbesondere des rindviehes [The detrimental effect of lead mines on the health of animals, especially those with horns]: Berlin, Germany, Veit and Company, 63 p. [In German.] [Also available at https://books.google.com/books?id=5rw9AAAAcAAJ&printsec=frontcover&hl=en&sa=X&ved=0ahUKEwi1y-iA_PPQAhVEQyYKHcpFC_sQ6AEIHzAA.]

Wetmore, Alexander, 1919, Lead poisoning in waterfowl: Washington, D.C., Bulletin of the U.S. Department of Agriculture, no. 793, 12 p.

Whitlock, S.C., and Miller, H.J., 1947, Gunshot wounds in ducks: Journal of Wildlife Management, v. 11, no. 3, p. 279–281. [Also available at http://dx.doi.org/10.2307/3796289.]

Patuxent Researchers Tackle Heavy Metal Poisoning in Wildlife

By Gary H. Heinz

An Early Memory

When I first arrived at the Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, in 1969, I saw a device that resembled a small railroad track out in a field. When I asked what it was, I was told it was a trolley on which tethered game-farm mallard ducks (*Anas platyrhynchos*) were shuttled in front of a shotgun. Everything was automated: when the duck crossed a certain point, a perfectly aimed shotgun was fired. Jerry Longcore and his supervisor, Ralph Andrews, U.S. Fish and Wildlife Service (USFWS) biologists at the time, were comparing the killing efficiency of iron shotgun pellets and traditional lead pellets (Andrews and Longcore, 1969). They found that, at typical shooting distances, the iron shot were perfectly capable of killing a duck. At the time, such an experiment, in which more than 2,000 ducks were being sent in front of a shotgun to be killed—and some only badly wounded—did not raise any questions in my mind. Today, if such an experiment were to be proposed and submitted to our Animal Care and Use Committee, I strongly doubt it would be approved; however, back then, it was approved and the results of this scientific "duck killing experiment" were critical in saving millions of ducks and other waterfowl from dying each year from lead-shot poisoning.

Jerry Longcore was only one of many hard-working and dedicated research scientists who proved that lead was killing millions of waterfowl each year when the birds inadvertently swallowed the shot from the bottoms of marshes across the country. They not only showed that it was the swallowing of lead shotgun pellets that killed the birds, they also paved the way for the eventual banning of lead shot from waterfowl hunting.

Purpose and Scope

First, I am not attempting to review the entire history of Patuxent's research on heavy metals. That could be a book in itself. I want to tell a short story that is not mired in all the heavy metals that were studied at Patuxent and all the publications that resulted from those studies. This story is as much about the people who studied heavy metals like lead as it is about the findings from their studies.

In this chapter, I share two often unappreciated observations: (1) it takes a surprisingly large group of dedicated researchers many years to bring about a change such as the banning of lead shot; and (2) even when one problem with a particular heavy metal, like lead shot, has been solved, different problems with the same heavy metal commonly surface down the road, and their solution can require an equally great effort.

Why Focus on Lead?

Why am I writing about lead contamination? First, I have personally been involved with some studies on lead, so I am familiar with lead toxicity. Second, studies on lead represent some of Patuxent's most important contributions to solving contaminant problems, and success stories are what contaminant research is supposed to be all about.

For many years, I lived in a house on the Patuxent Research Refuge (Patuxent's original name). One day my son, Brian, who was about 10 years old at the time, was out with two of his neighbor friends, Nate and Ben, exploring the marshes and ponds that dot Patuxent. They found a dead Canada goose (*Branta canadensis*) and brought it up to our house, asking me why I thought it had died. To give them a lesson in biology, I got a knife and I opened the goose. Everything looked normal. It had lots of fat. I did not see any injuries. I began to identify for them all the internal organs—here is the heart, here is the liver, the lungs, and so forth. Here is the gizzard. So they asked, "What is the gizzard for? Why is it so big? Do all animals have one?" "Well," I said, "I will open it up and tell you."

As I slit through the muscular wall of the gizzard, the metal of the knife made a strange sound, like metal scraping against metal. Inside was the normal assortment of sand-sized to small-gravel-sized grit. To my surprise, however, mixed in with that grit was a total of 518 shotgun pellets, plus a half-dozen small lead fragments. Some of these pellets were rusted and, suspecting they were steel shot, I used a magnet and determined that 55 of the shot were, in fact, steel, but the remaining 463 were very small lead pellets—about size 9—that might be used to shoot clay pigeons at a trap and skeet range. I guessed that this bird had been feeding at such a range and had picked up the shot, mistaking them for the grit it was seeking.

None of the shot had been eroded out of the normal, round shape into the flattened, disk-shaped pieces one typically finds in a bird that has survived long enough to have its gizzard grind away at the pellets. The several small lead fragments I found were probably pieces of lead shot that were created by collisions of the shot with other shot as they exited the shotgun barrel or as they collided with the clay pigeons they hit. The lack of erosion of the lead pellets, plus the fact that this goose had not progressed through the typical lead-poisoning phase of weight loss, suggested to me that the dose of lead shot likely was so massive that the bird had died of rapid, acute poisoning.

Holly Obrecht, our refuge biologist, told me he had found many dead geese that year, all with lead pellets in them. Holly sampled the mud on the bottoms of local marshes and visited local shooting ranges, trying to find the place where these geese had picked up their pellets, but he could never locate the source of all this lead shot. To my knowledge, all these years later, no one has ever found it.

Lead-Shot Research

Long before my son and his friends found the dead Canada goose, Patuxent researchers knew the same thing: ingesting lead pellets, even a few, can kill a bird. In 1951, Dr. Don Coburn and his coworkers published a paper in "The Journal of Wildlife Management" (Coburn and others, 1951) describing the toxicity of lead to mallards. A laboratory building at Patuxent was later named after Coburn and, for several decades, Coburn Laboratory was used for the study of the effects of lead and many other contaminants on birds.

In the 1960s, Lou Locke, the Patuxent veterinarian, and his coworkers George Bagley and H.D. Irby reported on the histopathological effects of ingested lead shot on mallards, leading the way in showing how to identify lead poisoning in dead birds (Locke and others, 1966; Locke and others, 1967). Lou was fun to be around and seemed to be at his happiest when he was examining a dead bird to determine what had killed it. In the late 1960s, interest rose in finding a metal that could be formed into shotgun pellets and was not toxic to waterfowl. Soft-iron pellets (later called "steel shot") were determined to be satisfactory, as discussed above (Andrews and Longcore, 1969). In one Patuxent study, nine different types of shotgun pellets were compared for their toxicity to mallards (Irby and others, 1967). Simply coating lead pellets with plastic did nothing to reduce their toxicity, as the plastic was ground off in the gizzard; iron and copper shot, however, were nontoxic. Patuxent biologists also discovered that mourning doves (*Zenaida macroura*) could be exposed to lead shot, presumably mistaking them for grit (Locke and Bagley, 1967); therefore, other birds in addition to waterfowl were at risk.

In the 1970s, Patuxent scientists continued the research on lead-shot poisoning of birds. Wildlife biologist Mack Finley and physiologist Mike Dieter determined that merely mixing iron with the ballistically superior lead to make shotgun pellets did not completely resolve the poisoning problem (Finley and Dieter, 1978). Finley and Dieter joined with Lou Locke to show that lead-shot poisoning could be diagnosed by measuring an enzyme (delta-aminolevulinic acid dehydratase, or ALAD) in the blood of ducks (Finley and others, 1976). At about the same time, Patuxent scientists were in the field, determining the number of waterfowl being exposed to lead shot (White and Stendell, 1977; Stendell and others, 1979). Don White was a "no-nonsense" wildlife biologist who completed a study and promptly published it, then completed another study and published it; he was efficient and hard working. Rey Stendell went on to become a laboratory director at another U.S. Fish and Wildlife Service Research Center. An unusually large number of Patuxent scientists—I can think of nine off the top of my head—went on to become laboratory directors. I am not sure what that means; personally, I believe it indicates that Patuxent was a good training ground for future leaders, but perhaps there are other interpretations as well.

Biologists who were not in the contaminants program, but who did important work on lead shot, were frequently at Patuxent. For example, Joe Artmann and Woody Martin were never in the contaminants program and I do not think they did any other contaminant research, but they discovered that the sora rail (*Porzana carolina*) was another species that was ingesting lead shot in marshes (Artmann and Martin, 1975).

In the 1980s, Barnett Rattner and his colleagues determined that wild American black ducks (*Anas rubripes*) seemed to be more sensitive to lead poisoning than were game-farm mallards (Rattner and others, 1989). Barnett was a highly

Joe Artmann (left) and Woody Martin, U.S. Fish and Wildlife Service, on rail study in Patuxent River marshes, Maryland, 1976. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Tundra swans killed by lead in sediments of Coeur d'Alene River, ID, 1991. Photo by Dan Audet, U.S. Fish and Wildlife Service.

trained physiologist who blended his academic skills with an expanding interest in wildlife biology—a transition similar to the paths that many wildlife biologists took toward a career in wildlife toxicology. Such blending of talents and interests was common in those days, when few professionals were actually academically trained in what is now called ecotoxicology. In his office, Barnett has a picture of a double-crested cormorant (*Phalacrocorax auritus*) he shot for contaminant analysis; not bad for a physiologist. In 2012, Barnett started his term as president of the Society of Environmental Toxicology and Chemistry, the largest professional society in the world dedicated to studying the effects of environmental contaminants on wildlife. This was a great honor for him and for Patuxent.

In one example of how Patuxent scientists with various academic backgrounds joined forces to study lead-shot poisoning, Chris Franson, a veterinarian at Patuxent, teamed up with Mike Haramis and Matt Perry, both wildlife field biologists, and John Moore, a chemist, to measure protoporphyrin (a precursor to hemoglobin in the blood) to reveal how many canvasbacks (*Aythya valisineria*) had been exposed to lead shot (Franson and others, 1986). Hank Pattee, who was an avid duck hunter and wholeheartedly embraced the transition to steel shot, demonstrated that predatory birds such as bald eagles (*Haliaeetus leucocephalus*) could be poisoned by eating lead-poisoned ducks (Pattee and Hennes, 1983).

The studies mentioned above are only a fraction of the work done at Patuxent to verify the threat of lead pellets to birds. It was not until 1991 that lead shot was banned for waterfowl hunting in the United States. From the first Patuxent study back in 1951 by Don Coburn, it had taken 40 years of dedicated research, not only by Patuxent scientists but also by a legion of other scientists, to gather enough convincing information to ban lead shot. However, the decades of work were well spent, as millions of waterfowl and other birds were spared death caused by ingestion of lead shot. As the development of nontoxic substitute shot expanded beyond the iron shot tested years earlier by Jerry Longcore, Barnett Rattner at Patuxent was designated as the scientist who would review the toxicity data generated for each of these proposed substitutes, making sure they would not pose a risk to birds.

So, With Lead Shot Banned, We Have Solved the Lead Problem, Right?

Unfortunately, no! Although lead shot was banned for waterfowl hunting in this country, there was no way to ban lead itself. The first problem with lead not associated with lead shot that came to the attention of Patuxent scientists was the emission of lead from leaded gasoline. Could lead from this source get into wildlife? To determine whether lead from vehicle emissions was getting into wildlife, Chris Grue, Dave Hoffman, and Nelson Beyer measured lead concentrations in the tissues of European starlings (*Sturnus vulgaris*) nesting near heavily used roads and in starlings nesting next to little-used roads at Patuxent. Lead concentrations were several times higher in starlings living near the heavily used roads, but reproductive success was not different (Grue and others, 1986). With the phasing out of leaded gasoline between 1975 and 1986, lead from gasoline ceased to be a source of lead in wildlife.

In the 1990s, Patuxent scientists began studying still another dangerous source of lead—mining operations. This work initially focused on lead contamination of the Coeur d'Alene River in Idaho. Each year, about 150 tundra swans (*Cygnus columbianus*) with lead poisoning would be found in the Coeur d'Alene River Basin. More than a century of mining operations left the sediments in much of the Coeur d'Alene River contaminated with lead. At first, lead was suspected to have moved up the food chain, as many contaminants do kill birds this way; however, studies with ospreys (*Pandion haliaetus*) by Chuck Henny and Larry Blus at Patuxent's Corvallis, OR, field station demonstrated that lead was not moving up the food chain (Henny and others, 1991). Henny was a field biologist with a remarkable ability to detect previously unrecognized contaminant problems. Blus had already made his own mark decades earlier, demonstrating that dichlorodiphenyldichloroethylene (DDE), the metabolite of the pesticide dichlorodiphenyltrichloroethane (DDT), thinned the eggshells of brown pelicans (*Pelecanus occidentalis*).

Follow-up fieldwork by Henny and Blus strongly indicated that the tundra swans were getting their lethal dose of lead because they ingested some lead-contaminated sediment along with food they had gleaned off the bottom of marshes (Blus and others, 1991). To prove that the ingestion of lead-contaminated sediments was poisoning waterfowl at the Coeur d'Alene River, however, a series of controlled laboratory studies was needed. As is usually the case with contaminant problems affecting wildlife, a coordinated combination of field and laboratory studies is needed to fully understand the processes at work.

Back at Patuxent headquarters, a series of controlled feeding studies was conducted in which Coeur d'Alene River sediment was mixed into waterfowl diets at rates comparable to the sediment ingestion rates of wild birds. These studies proved that sediments collected from the Coeur d'Alene River contained enough lead to poison mallards, Canada geese, and mute swans (*Cygnus olor*); the mute swan served as a surrogate for the tundra swan (Heinz and others, 1999; Hoffman and others, 2000; Day and others, 2003).

The studies Patuxent scientists carried out on lead poisoning in Idaho were part of a Natural Resource Damage Assessment (NRDA) by the U.S. Department of the Interior (DOI). A NRDA is a legal process the DOI established to determine the degree of restoration needed to compensate the public for harm to natural resources because of the release of a hazardous substance into the environment. A court settlement was reached in the case of the mining companies that had released lead-contaminated sediments into the Coeur d'Alene River in Idaho. Approximately $370 million was awarded to clean up the Coeur d'Alene River Basin. This large court settlement validated the years of field and laboratory research carried out by Patuxent scientists and scientists from the USFWS. It is this kind of success story about contaminant research that gives scientists at Patuxent a great deal of pride, whether the success resulted from our contributions to the banning of lead shotgun pellets or led to the cleanup of a lead-contaminated river.

I mentioned at the outset of this chapter that it commonly takes a large and dedicated staff of researchers many years to bring about the resolution of a contaminant issue. This was clearly true of the various forms of lead contamination we studied over many decades at Patuxent. No one can be sure that some other source of lead contamination will not arise in the future that presents an equal research challenge. As I reflect on those "railroad tracks" I first saw in 1969—the tracks on which all those mallards were sent to be shot—I realize that Patuxent scientists of all kinds and with different training were up to the task of determining just what the contaminant issue was and how it might be solved. I feel privileged to have known them.

References Cited

Andrews, Ralph, and Longcore, J.R., 1969, The killing efficiency of soft iron shot: Transactions of the North American Wildlife and Natural Resources Conference, v. 34, p. 337–345.

Artmann, J.W., and Martin, E.M., 1975, Incidence of ingested lead shot in sora rails: Journal of Wildlife Management, v. 39, no. 3, p. 514–519. [Also available at http://www.jstor.org/stable/3800393.]

Blus, L.J., Henny, C.J., Hoffman, D.J., and Grove, R.A., 1991, Lead toxicosis in tundra swans near a mining and smelting complex in northern Idaho: Archives of Environmental Contamination and Toxicology, v. 21, p. 549–555. [Also available at http://dx.doi.org/10.1007/BF01183877.]

Coburn, D.R., Metzler, D.W., and Treichler, Ray, 1951, A study of absorption and retention of lead in wild waterfowl in relation to clinical evidence of lead poisoning: Journal of Wildlife Management, v. 15, no. 2, p. 186–192. [Also available at http://www.jstor.org/stable/3796607.]

Day, D.D., Beyer, W.N., Hoffman, D.J., Morton, A., Sileo, Louis, Audet, D.J., and Ottinger, M.A., 2003, Toxicity of lead-contaminated sediment to mute swans: Archives of Environmental Contamination and Toxicology, v. 44, no. 4, p. 510–522. [Also available at http://link.springer.com/article/10.1007%2Fs00244-002-1140-4.]

Finley, M.T., and Dieter, M.D., 1978, Toxicity of experimental lead-iron shot versus commercial lead shot in mallards: Journal of Wildlife Management, v. 42, no. 1, p. 32–39. [Also available at http://www.jstor.org/stable/3800686.]

Finley, M.T., Dieter, M.D., and Locke, L.N., 1976, δ-Aminolevulinic acid dehydratase—Inhibition in ducks dosed with lead shot: Environmental Research, v. 12, no. 2, p. 243–249. [Also available at http://www.sciencedirect.com/science/article/pii/0013935176900323.]

Franson, J.C., Haramis, G.M., Perry, M.C., and Moore, J.F., 1986, Blood protoporphyrin for detecting lead exposure in canvasbacks, *in* Feierabend, J.S., and Russell, A.B., eds., Lead poisoning in wild waterfowl—A workshop: Washington, D.C., National Wildlife Federation, p. 32–37. [Also available at https://www.researchgate.net/publication/277712385_Blood_protoporphyrin_for_detecting_lead_exposure_in_canvasbacks.]

Grue, C.E., Hoffman, D.J., Beyer, W.N., and Franson, L.P., 1986, Lead concentrations and reproductive success in European starlings *Sturnus vulgaris* nesting within highway roadside verges: Environmental Pollution, v. 42, no. 2, p. 157–182. [Also available at http://www.sciencedirect.com/science/article/pii/014314718690005X.]

Heinz, G.H., Hoffman, D.J., Sileo, Louis, Audet, D.J., and LeCaptain, L.J., 1999, Toxicity of lead-contaminated sediments to mallards: Archives of Environmental Contamination and Toxicology, v. 36, no. 3, p. 323–333. [Also available at http://link.springer.com/article/10.1007%2Fs002449900478.]

Henny, C.J., Blus, L.J., Hoffman, D.J., Grove, R.A., and Hatfield, J.S., 1991, Lead accumulation and osprey production near a mining site on the Coeur d'Alene River, Idaho: Archives of Environmental Contamination and Toxicology, v. 21, no. 3, p. 415–424. [Also available at http://link.springer.com/article/10.1007%2FBF01060365.]

Hoffman, D.J., Heinz, G.H., Sileo, Louis, Audet, D.J., Campbell, J.K., LeCaptain, L.J., and Obrecht, H.H., III, 2000, Developmental toxicity of lead-contaminated sediment in Canada geese (*Branta canadensis*): Journal of Toxicology and Environmental Health, v. 59, p. 235–252. [Also available at http://dx.doi.org/10.1080/009841000156916.]

Irby, H.D., Locke, L.N., and Bagley, G.E., 1967, Relative toxicity of lead and selected substitute shot types to game farm mallards: Journal of Wildlife Management, v. 31, no. 2, p. 253–257. [Also available at http://www.jstor.org/stable/3798314.]

Locke, L.N., and Bagley, G.E., 1967, Lead poisoning in a sample of Maryland mourning doves: Journal of Wildlife Management, v. 31, no. 3, p. 515–518. [Also available at http://www.jstor.org/stable/3798133.]

Locke, L.N., Bagley, G.E., and Irby, H.D., 1966, Acid-fast intranuclear inclusion bodies in the kidneys of mallards fed lead shot: Bulletin of the Wildlife Disease Association, v. 2, no. 4, p. 127–131. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-2.4.127.]

Locke, L.N., Irby, H.D., and. Bagley, G.E., 1967, Histopathology of mallards dosed with lead and selected substitute shot: Bulletin of the Wildlife Disease Association, v. 3, no. 4, p. 143–147. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-3.4.143.]

Pattee, O.H., and Hennes, S.K., 1983, Bald eagles and waterfowl—The lead shot connection: Transactions of the North American Wildlife and Natural Resources Conference, v. 48, p. 230–237.

Rattner, B.A., Fleming, W.J., and Bunck, C.M., 1989, Comparative toxicity of lead shot in black ducks (*Anas rubripes*) and mallards (*Anas platyrhynchos*): Journal of Wildlife Diseases, v. 25, no. 2, p. 175–183. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-25.2.175.]

Stendell, R.C., Smith, R.I., Burnham, K.P., and Christensen, R.E., 1979, Exposure of waterfowl to lead—A nationwide survey of residues in wing bones of seven species, 1972–73: U.S. Fish and Wildlife Service Special Scientific Report—Wildlife, no. 223, 12 p. [Also available at https://archive.org/details/specialscientifi223unit.]

White, D.H., and Stendell, R.C., 1977, Waterfowl exposure to lead and steel shot on selected hunting areas: Journal of Wildlife Management, v. 41, no. 3, p. 469–475. [Also available at http://www.jstor.org/stable/3800518.]

Gray squirrel in sycamore tree, Patuxent Research Refuge, Laurel, MD, 1973, Photo by Matthew C.Perry, U.S. Fish and Wildlife Service.

Role of Raptors in Contaminant Research at Patuxent

By Charles J. Henny

Introduction

This chapter reviews the history of and approaches used in studies focused on the effects of contaminants on raptors and raptor populations at the Patuxent Wildlife Research Center (Patuxent) in Laurel, MD. Worldwide raptor declines following World War II were unprecedented and resulted in a sequence of major efforts at Patuxent to understand their cause(s). The peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), and osprey (*Pandion haliaetus*) were the species of most concern in North America. Laboratory and field studies at Patuxent complemented each other and yielded timely results of national and international importance, including some findings published in the journals "Science" and "Nature."

Concern about contaminant effects on wildlife populations came to the forefront during the years immediately following World War II. This concern was worldwide and not limited to one taxonomic group or to personnel and investigations at Patuxent. Contaminant studies of raptors were only part of the story, but this review, with minor exceptions, is limited to raptor studies and the role Patuxent played in this research. Indeed, many important nonraptor contaminant studies done at Patuxent, as well as raptor studies conducted elsewhere, are not mentioned here. For other reviews of contaminant-wildlife issues in the 1950s and 1960s, the reader is referred to "Silent Spring" by Rachel Carson (1962), "Pesticides and the Living Landscape" by Robert Rudd (1964), and "Return of the Peregrine: A North American Saga of Tenacity and Teamwork" by Tom Cade and Bill Burnham (Cade and Burnham, 2003).

Early Years (Pre-1960)

Before 1960, few raptor studies were conducted at Patuxent or by personnel stationed there. The notable exception is the long-term red-shouldered hawk (*Buteo lineatus*) study

Chuck Henny, U.S. Fish and Wildlife Service, with young red-shouldered hawk at Patuxent Wildlife Research Center, Laurel, MD, 1972. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

along the Patuxent River flood plain, initiated by Bob Stewart in 1943 (Stewart, 1949) and continued by Henny and others (1973) and Martin (2004). The study, which continues today (2016), was designed to improve understanding of habitat requirements, population densities, reproductive rates, and food habits, although a few eggs were analyzed for contaminants recently. Contaminant levels in eggs were generally low in the early 1970s, but habitat loss resulted in a long-term population decline of 78 percent from 1971 to 2002. Other studies prior to 1960 involved the development of techniques for live-trapping hawks and owls (Stewart and others, 1945) and the reporting of hawk migration count data (Robbins, 1950, 1956).

Raptor Pesticide Studies (1960–64)

The early 1960s brought the issues of raptor population declines and pesticides together. Earlier, James DeWitt (1956) at Patuxent had reported that pheasants and quail exposed to several pesticides in controlled laboratory conditions laid fewer eggs and produced fewer chicks than birds not exposed to pesticides, a finding that caused considerable concern among conservationists. Robbins (1960) evaluated the status of the bald eagle in summer 1959 by compiling information from the U.S. Fish and Wildlife Service (USFWS), State organizations, National Audubon Society, and private individuals. Charles Broley's 20-year bald eagle dataset from the west coast of Florida was particularly alarming (Broley, 1958); it showed a 50- to 90-percent population decline, with markedly decreasing productivity rates after 1946. Broley (1958) and Robbins (1960) pointed out that Maurice Broun's fall migration count data from Hawk Mountain Sanctuary in Pennsylvania showed that during 1935–40, 38 percent of the bald eagles migrating over the sanctuary were in immature plumage, but during the last 6 years of the study (1953–58), the percentage of immatures was only 21 percent. The percentage was especially low (10 percent) during 1957–58.

DeWitt and Buckley (1962), in an interim report, noted that definitive proof of the cause(s) of the bald eagle population declines and lowered reproductive success was lacking, although it was postulated that prolonged and continued exposure to dichlorodiphenyltrichloroethane (DDT) and related pesticides might have been responsible. Bald eagles were trapped in Alaska in 1961 and 1962, brought into captivity at Patuxent, and fed various diets of DDT. These 1961–62 feeding experiments demonstrated that DDT could kill bald eagles. By 1963, Patuxent had obtained 54 dead bald eagles and 5 unhatched eggs. All but one bird (from Alaska) contained detectable DDT residues (Buckley and DeWitt, 1963). Buckley and DeWitt (1963) concluded (1) wild eagles carry body burdens of DDT, but they were uncertain whether burdens in wild eagles were sufficiently high to be detrimental; and (2) all eggs analyzed contained DDT residues, indicating that some DDT was transferred to the egg, but they were uncertain whether DDT levels measured in the eggs affected hatching.

Peregrine Falcon Conference (1965)

The Peregrine Falcon Conference held in Madison, WI, in 1965 (Hickey, 1969) was a landmark event. Joe Hickey (University of Wisconsin) had organized a 1964 repeat of his 1939–40 Peregrine Falcon Survey in the Eastern United States (east of the Mississippi River). Hickey's (1942) data plus data from several additional sites yielded 209 perceived "valid" eyries, but Berger and others (1969), who checked 133 sites, found no occupied peregrine falcon eyries in 1964. The surveyors realized the impossibility of thoroughly covering the survey area, but emphasized that the species, if not extirpated in the United States east of the Mississippi River, was drastically reduced. Ratcliffe (1969) noted a sequence of peregrine falcon population declines in Great Britain that included egg breakage, egg-hatching failure, death of young, and failure of adults to lay eggs, which preceded actual desertion of the territory. Eggs from 14 peregrine falcons all contained residues of DDT/ dichlorodiphenyldichloroethylene (DDE, a metabolite of DDT), benzene hexachloride (BHC), dieldrin, and heptachlor epoxide, and Derek Ratcliffe, chief scientist, Nature Conservancy Council, United Kingdom, argued that concentrations in some were sufficient to account for sublethal effects leading to reduced breeding success. Similar population declines and low productivity were reported for ospreys in Connecticut (Peterson, 1969) and Michigan (Postupalsky, 1969).

John Buckley, former director of Patuxent, led a roundtable discussion on "pesticides as possible factors affecting raptor populations" with Joe Hickey, Ian Prestt, Lucille Stickel, and Bill Stickel. The primary focus was to review "what we know" and to identify "what we do not know" in 1965. Lucille and Bill Stickel took an active role in the discussions (Hickey, 1969) and listed several tentative conclusions: (1) birds may have normal or near-normal reproductive success despite relatively high DDT residues in eggs (this was later recognized to occur with insensitive species); (2) there is no evidence that a few parts per million (ppm) of DDT in eggs causes reproductive trouble; (3) chlorinated hydrocarbon dosages that clearly reduce avian reproduction are, with possible exceptions, not far below those that will kill some birds if continued; (4) long-term intake of small doses is far more lethal than once thought; (5) declines in avian reproductive success with insecticidal dosages are almost always partial, are typically small, and are rarely eliminative; and (6) it is not characteristic of DDT, dieldrin, or most other chlorinated hydrocarbons to kill birds or to block reproduction without leaving residues that are substantial in relation to the toxicity of the chemicals involved—for example, DDT levels representing serious damage to birds will be well above 2 or 3 ppm of total residues. The Stickels noted that it was necessary to deal with these questions because there was still a strong tendency to attach much importance to low DDT residues, or pesticides in general, when we could have been missing the real causes of the population declines.

Early Patuxent field studies with DDT at application rates of 2 to 5 pounds per acre (Hotchkiss and Pough, 1946; Stewart and others, 1946; Robbins and Stewart, 1949; Robbins and others, 1951; Mitchell and others, 1953) resulted in mixed findings regarding effects on passerine bird populations. The Stickels at the round-table discussion further noted that although pesticides kill wildlife and may cause population declines, many other factors—for example, disease and metals, such as mercury and lead—do so as well. They concluded that more work was required in the study of behavioral effects and combinations of pesticides, and more wild species needed to be tested because sensitivity to contaminants differs greatly among species.

Regarding procedural matters, Lucille Stickel noted a serious bias when eggs were collected for residue analysis (especially failed eggs from nests) and suggested using the volume of the egg in its shell as an adjustment for moisture loss. This suggestion was first mentioned in 1965 (Stickel and others, 1965); a detailed paper (Stickel and others, 1973) was published 8 years later. Without the adjustment, residue concentrations on a wet-weight basis were inflated, commonly by 50 percent or more. Some researchers today (2016) still make this mistake when reporting egg residues. Lucille believed the only way to verify lethal concentrations of contaminants in hawks was experimentally—that is, feed the birds a diet that contains the pesticide of concern while maintaining suitable controls. She also pointed out that birds that died during the lab experiments with DDT and DDE had brain concentrations of the same magnitude whether they died immediately or after months on clean food. Because concentrations in other tissues were highly variable, Patuxent recommended that, for diagnostic purposes, brain concentrations be used to establish the cause of death from chlorinated hydrocarbons (Stickel and others, 1969; Stickel and others, 1970). The Stickels downplayed the importance of egg breakage at this time (1965), and noted that it was not uncommon in captivity, even with birds not on dose.

Rapid Increase in Contaminant Studies (1966–90)

The pesticide-eagle studies at Patuxent by Buckley and DeWitt (1963) mentioned earlier were updated at the North American Wildlife and Natural Resources Conference by Stickel and others (1966), who concluded that (1) pesticide residue transfer from adult to egg is well known; (2) the quantity of residues that may indicate an adverse effect on hatching and survival is far from clear (but they noted that quantities of DDE, DDT, and dichlorodiphenyldichloroethane (DDD) in eagle eggs so far reported are much lower than those reported in gull and pheasant eggs that hatched or were alive, which provides little basis for suspecting that DDT in eggs prevented hatching); (3) exposure of eagles to DDT and dieldrin is nationwide; (4) at least an occasional eagle obtains enough dieldrin, and perhaps DDT, to place it at risk; and (5) most eagles that die in the United States today die of causes other than pesticide poisoning. Finally, the important question of sublethal effects on behavior, particularly parental behavior, could not yet be answered. Future research plans at Patuxent were also mentioned; they included (1) continue monitoring eagle eggs and adults for pesticide residues, (2) extend analyses to some of the more important heavy metals, (3) begin food-chain investigations specific to eagles, and (4) improve understanding of residues in eggs and tissues (Patuxent already had established a colony of American kestrels [*Falco sparverius*] to test for reproductive effects with a raptor).

Additional Patuxent field data on raptor populations were reported when Schmid (1966) compared the number of successful osprey nests and young banded per successful nest in parts of Cape May County, NJ, in 1937, 1938, and 1939 with numbers observed in 1963. This one-trip visit at banding time, of course, did not include those nests that failed, although the number of successful nests had decreased dramatically (perhaps by 60–70 percent) by 1963. Schmid concluded that possible explanations might be diminishing food supply, contaminants in the food chain, or a growing frequency of disturbance and persecution. Subsequent Patuxent field studies emphasized a much more detailed approach, which included methods for separating several of the possible factors that could cause population declines (for example, see the section below titled "Osprey" for a description of the osprey egg transfer study between Connecticut and Maryland).

At the time of the Peregrine Falcon Conference in 1965, eggshell thinning was not yet known; only the alarming and rapid declines of the peregrine and their unusual behaviors were recognized at many locations. No conclusions had yet been reached regarding the cause(s) of the declines at the 1965 conference. Egg breakage was mentioned as one of the many factors that needed to be considered in evaluating worldwide peregrine population declines. Derek Ratcliffe left the conference with egg breakage on his mind and then talked with Desmond Nethersole-Thompson—a long-time friend of his, a field biologist, and an early egg collector—who suggested that Ratcliffe look at eggs in collections. Desmond's suggestion was critical and led to the first understanding that eggshells themselves were affected along with, of course, the females that laid those eggs. Ratcliffe devised an eggshell "thickness index" because he could not directly measure eggshell thickness; the oologists who collected the eggs and removed the contents of the eggs prided themselves on making a very small hole in the eggshell. Ratcliffe reported his astounding results that eggshells were now thinner than in the past to Joe Hickey, professor at the University of Wisconsin, even before he went to press in "Nature." Ratcliffe and Hickey were friends and talked on the phone often. Dan Anderson, a graduate student working with Hickey, was immediately sent to many museums in the United States to measure eggshell thickness with a modified micrometer that would fit through the tiny holes the egg collectors made (Daniel Anderson, University of California, Davis, oral commun., 2012). Hickey, whose long association with Patuxent dated back to his early studies of banding data from the Bird Banding Laboratory (Hickey, 1952), obtained USFWS funding for the eggshell-thickness project through Patuxent and Lucille Stickel.

Thus, Ratcliffe (1967), while investigating the peregrine falcon and sparrow hawk (*Accipiter nisus*) in the United Kingdom, noted a relation between decreases in eggshell weights, decreases in sizes of breeding populations, and exposure of populations of these species to persistent organic insecticides. Hickey and Anderson (1968) reported similar findings for North American species the next year. The observation was that eggshell thinning in archived samples of raptor eggs and other species had occurred over a critical time, namely the period coincident with the post-World War II introductions of organochlorine (OC) pesticides and radioactive contamination; this was an important discovery. The next step involved a hypothesis that DDT (later discovered to be DDE) was the major cause of eggshell thinning and that this eggshell thinning was related to population declines through reduced reproductive success. The critical step was the testing for effects of DDT and dieldrin on eggshell thinning and reproduction of American kestrels at Patuxent under controlled laboratory conditions (Porter and Wiemeyer, 1969; Wiemeyer and Porter, 1970). These controlled studies showed the same pattern of reproductive failure and reduced eggshell thickness that appeared in several raptor populations in the United States and Western Europe. This early laboratory work was completed under the direction of Lucille Stickel, whose leadership and insight, in addition to her command of the necessary resources for critical experiments, made it possible.

Young eaglet in captive study at Patuxent Wildlife Research Center, Laurel, MD, 1970s. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Brown pelican egg without eggshell, 1970s. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Eggshell thickness was an increasingly important factor and was studied intensively under controlled conditions at Patuxent. Thus, much of the work at Patuxent followed general concepts developed by the Stickels prior to 1965, with slight modifications—for example, eggshell thinning came to be considered much more important than had been anticipated in earlier years. One outcome of the discovery of eggshell thinning was the realization that in studying other contaminants it was beneficial also to study not only mortality, but also the subtle, insidious effects of the contaminants. Many of the people employed at Patuxent after 1965 were hired specifically to conduct various types of studies to complete missing parts of the contaminant story, not only for raptors, but also for all wildlife. Later studies extended to groups of contaminants other than OCs, including organophosphates (OPs), carbamates, anticoagulants, mercury, lead, selenium, fluoride, cadmium, flame retardants, chlorophenoxy herbicides, perfluorinated acids, and sulfates, as well as combinations of chemicals.

Laboratory Studies

The laboratory studies at Patuxent with American kestrels (table 1), eastern screech owls (*Otus asio*), and common barn owls (*Tyto alba*) (table 2) were many and involved many contaminants and endpoints. The compilation of reproductive-success and egg-residue data in a series of papers on a nest-by-nest basis in the laboratory and field (see Blus [1984] for the sample egg approach) was used to estimate the proportion of a population adversely affected by various contaminants—for example, the percentage of eggs containing concentrations greater than a perceived critical level for reproductive effects (table 3). The critical residue concentration information was especially useful to the field biologist who was trying to interpret observed local contaminant concentrations.

Table 1. Patuxent Wildlife Research Center laboratory studies on contaminants in American kestrels, 1969–2011.

[DDT, dichlorodiphenyltrichloroethane; DDE, dichlorodiphenyldichloroethylene; PCB, polychlorinated biphenyl; anti-ChE, anti-cholinesterase; PBDE, polybrominated diphenyl ether; OP, organophosphate; OC, organochlorine]

Contaminant(s)	Year(s) studied
Dieldrin + DDT	1969
Dieldrin + DDT, DDE	1970
DDE	1970
DDE	1972
Lead	1980
Parathion	1982
Oil	1982
Lead	1983
Lead	1984
Lead	1984
Methyl parathion, fenvalerate	1984
Lead	1985
Lead	1985
DDE, DDT + dieldrin	1986
Paraquat	1987
Lead + OCs	1989
Dicofol (kelthane)	1990
Diphenyl ether herbicides	1991
Aroclor 1248	1991
Four anti-ChEs	1991
PCB 126	1996
White phosphorus	1997
Aroclor 1248	1998
Planar PCBs	1998
OPs, carbamates	1998
Dicofol (kelthane)	2001
Aroclor 1242	2002
PBDEs	2005
Methylmercury	2007
Methylmercury	2009
PBDEs	2009
Methylmercury	2010, 2011
Diphacinone	2011

Table 2. Patuxent Wildlife Research Center laboratory studies on contaminants in eastern screech owl (*Otus asio*) and common barn owl (*Tyto alba*), 1972–98.

[DDE, dichlorodiphenyldichloroethylene; anti-ChE, anti-cholinesterase; OP, organophosphate]

Species	Contaminant(s)	Year studied
Eastern screech owl	DDE	1972
Eastern screech owl	Aroclor 1248	1980
Common barn owl	Famphur	1980
Common barn owl	Six anti-coagulants	1980
Eastern screech owl	Endrin	1982
Common barn owl	DDE, dieldrin	1983
Eastern screech owl	Fluoride	1985
Eastern screech owl	Fluoride	1988
Eastern screech owl	Dicofol (kelthane)	1989
Eastern screech owl	Four anti-ChEs	1991
Eastern screech owl	Selenium	1996
Eastern screech owl	OPs, carbamates	1998

Matt Perry banding young American kestrel at Patuxent Wildlife Research Center, Laurel, MD, 1975. Photo by U.S. Fish and Wildlife Service.

Table 3. Patuxent Wildlife Research Center studies[1] to determine the effect of contaminant residue concentrations in eggs on productivity of various raptor species using the sample egg technique.

[DDT, dichlorodiphenyltrichloroethane; DDE, dichlorodiphenyldichloroethylene; PCB, polychlorinated biphenyl; OP, organophosphate; OC, organochlorine; Hg, mercury]

Species	Contaminant(s)	Author (Year)
American kestrel	Heptachlor epoxide	Henny and others (1983)
Bald eagle	OCs, PCBs, Hg	Wiemeyer and others (1984)
American kestrel	DDE, DDT, dieldrin	Wiemeyer and others (1986)
Osprey	OCs, PCBs, Hg	Wiemeyer and others (1988)
Bald eagle	OCs, PCBs, Hg	Wiemeyer and others (1993)

[1]The collection and analysis of an egg from a series of nests for these studies provided an approach to evaluate the percentage of individuals in a wild population whose reproduction was adversely affected by various contaminants.

John Maistrelli, U.S. Fish and Wildlife Service, transferring adult eagle at Patuxent Wildlife Research Center, Laurel, MD, 1976. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Field Studies and Monitoring

The status of several raptor species and various raptor populations was not well known in the late 1960s and 1970s. The concern focused strongly on the peregrine falcon, bald eagle, and osprey, all of which were prominently mentioned at the 1965 Peregrine Falcon Conference. In the mid-1960s, the peregrine falcon was already extirpated or nearly extirpated in the Eastern United States, and reintroduction was in progress. Given the devastating population declines in the Eastern United States, contaminant studies on peregrines at Patuxent focused on monitoring northern latitude breeding populations that migrated along the Atlantic Coast and the Texas coast by sampling blood to determine contaminant trends from 1978–2004 (see Henny and others, 1982; Henny and others, 2009). The nationwide bald eagle population had declined substantially and the species was very sensitive to disturbance at the nest; however, unhatched eggs and dead eagles were analyzed routinely at Patuxent. Therefore, the osprey became the obvious candidate for intensive field studies because it could be studied more easily in the wild.

Osprey

During the Peregrine Falcon Conference, exceptionally poor productivity or declining osprey numbers were reported for Long Island, NY; Connecticut; New Jersey; Rhode Island; Maine; Massachusetts; Wisconsin; and Michigan. Most localized studies that followed the conference included an evaluation of (1) reproductive success, (2) changes in population numbers over time (although few series with more than a decade of data were available), (3) contaminant residues in some eggs and fish, and (4) eggshell thickness. Because reproduction was the apparent "weak link" in the life cycle, the number of young fledged per nesting pair was considered of primary importance (table 4).

Structural modeling based on survival-rate estimates from banding data and life-history characteristics (funded by the Migratory Bird Populations Station [MBPS] at Patuxent) (Henny and Wight, 1969; Henny and others, 1970) was used to estimate a recruitment standard (0.95–1.30 young per nesting pair) needed to maintain a stable osprey population. At that time, most osprey populations were producing at what was considered extremely low rates, although the normal (or standard) rate was unknown. Observed production rates were compared to the standard rate, which was later lowered to 0.80 young per nesting pair on the basis of a comparison between the observed population response and the projected population response determined by using the model (Spitzer and others, 1983).

In 1968 and 1969, osprey eggs were exchanged between Connecticut (low reproduction) and Maryland (higher reproduction) nests to test the hypothesis that the decline in reproductive success of Connecticut ospreys was caused by something external to the eggs (Wiemeyer and others, 1975)—for example, recall the concerns mentioned above about food supply, persecution, and human disturbance in the 1960s. A cartoon of the era representing the egg exchange study is shown in figure 1. Incubation of Connecticut osprey eggs by Maryland ospreys did not improve the hatching rate. Maryland eggs incubated by Connecticut ospreys hatched at their normal rate. The results of the exchanges and associated observations indicate that the most probable cause of the poor reproduction in Connecticut ospreys was related to contamination of eggs—namely eggshell thinning and embryo mortality, and not to subtle behavioral effects on the incubating parents. Henny and Van Velzen (1972) found that ospreys from New York, New Jersey, and Maryland shared the same general wintering

Table 4. *A*, Breeding population changes and, *B*, productivity of ospreys along the North Atlantic Coast of the United States, 1945–75.

[Modified from Henny (1977); see Henny (1977) for more information, including citations for publications; >, greater than; NA, not available]

A. Breeding population changes of ospreys

Location	Number of occupied nests				
	Pre-1945	1960	1965	1970	1975
Gardiner's Island, New York	300	100	70	38	31
Connecticut River, Connecticut	200	71	13	4	1
Rhode Island	130	> 60	23	7	8
Total	**630**	**> 231**	**106**	**49**	**40**
Observed annual rate change (percent)		-6.5	-14.4	-14.3	-4.0

B. Productivity of ospreys

Location	Number of young fledged per occupied nest					
	1950–52	1953–57	1958–62	1963–67	1968–72	1973–75
Gardiner's Island, New York	1.19	0.83	0.75	0.16	0.53	0.68
Connecticut River, Connecticut	NA	0.37	0.23	0.33	0.25	0.00
Rhode Island	NA	NA	0.27	0.40	0.61	1.00
Total	**1.19**	**0.65**	**0.47**	**0.23**	**0.52**	**0.73**

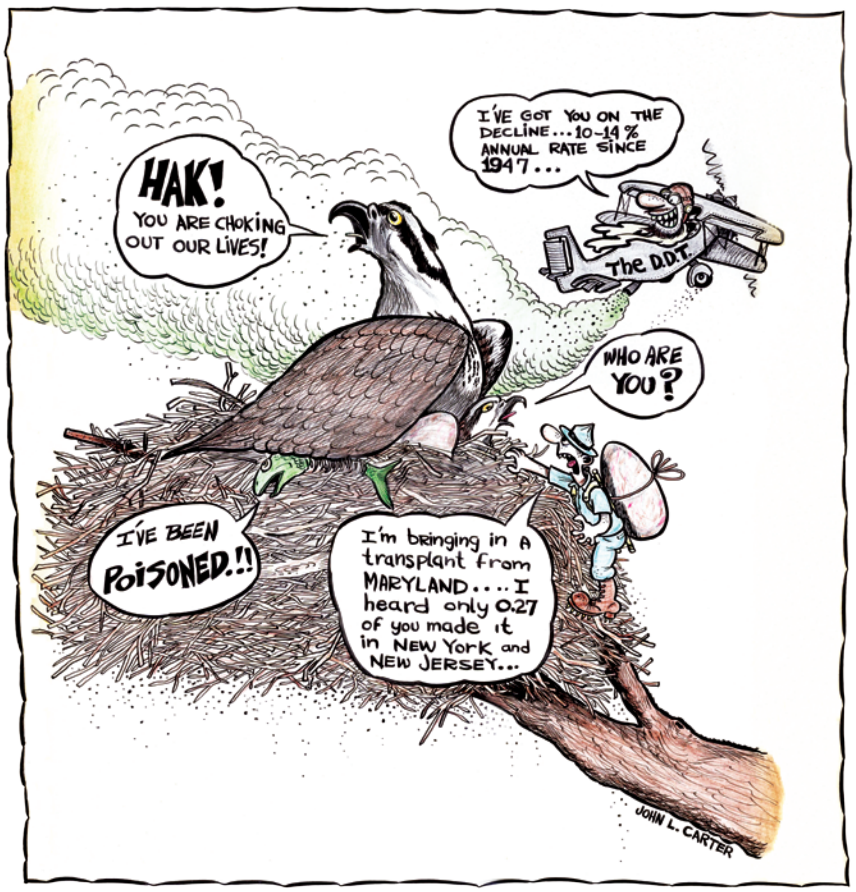

Figure 1. A cartoon of the early 1970s, which depicts the Patuxent Wildlife Research Center osprey egg exchange. (Cartoon by John L. Carter, a friend of the author, and used with his permission.)

grounds, which implied that local breeding success of an osprey population depended on environmental conditions in the breeding area. Their hypothesis was supported by the results of the egg exchanges, including the differences in OC residues in fish from the two osprey breeding areas. Average eggshell thickness of osprey eggs collected from Connecticut had declined 18 percent from pre-1947 norms, whereas that of eggs from Maryland had declined 10 percent (Wiemeyer and others, 1975).

In the late 1960s and early 1970s, the vision of the USFWS, including the MBPS located at Patuxent, was broadening to species other than migratory game species. Planes and experienced pilots were available for aerial surveys of nongame species if they did not conflict with breeding and wintering grounds waterfowl surveys. Therefore, the first USFWS aerial survey of nesting ospreys was conducted in Chesapeake Bay in 1973 (Henny and others, 1974). The survey was conducted much like a breeding ground survey of waterfowl with a double-sampling approach (both an overall air survey covering the entire area and ground surveys in a portion of the larger aerial survey area); this approach provided a total population estimate and its associated variance. Before the survey, both Chan Robbins (long-time Patuxent ornithologist) and Alexander Wetmore (long-time Smithsonian Institution ornithologist) believed that about 200 to 400 pairs of ospreys were nesting in Chesapeake Bay (Chandler Robbins, U.S. Fish and Wildlife Service, oral commun., 1973; Alexander Wetmore, Smithsonian Institution, oral commun., 1973), but the survey results indicated the estimated population in 1973 to be 1,450 pairs (Henny and others, 1974).

The Chesapeake Bay study was extended to the coastal Carolinas the next year (1974), and was followed in 1975 by studies of coastal New Jersey, Delaware, Maryland, and Virginia (Henny and Noltemeier, 1975; Henny and others, 1977). Similar osprey surveys were conducted in northern California in 1975, Oregon in 1976, and coastal northwestern Mexico (Baja California, Gulf of California, Sonora, and Sinaloa) in 1977 (Henny and others, 1978a, 1978b; Henny and Anderson, 1979). These surveys provided base values for future population comparisons.

Upon my return to Patuxent following the Carolina survey in 1974, I mentioned to Fran Uhler (long-time Patuxent biologist) that 38 pairs of ospreys were nesting in relatively short bald cypress trees (*Taxodium distichum*) in the lake at Mattamuskeet National Wildlife Refuge. Fran explained that the lake had been drained in 1914 to convert it to farmland, but the plan was later abandoned. Consequently, the lakebed was dry in 1928 when he surveyed it as a possible refuge site. In 1934, the U.S. Government acquired the land and a refuge was established. Increment borings of the cypress trees used as nest sites in 1974 placed their ages at 30 to 40 years, which corresponds to the period shortly after the land was acquired and reflooding began (Fran Uhler, U.S. Fish and Wildlife Service, oral commun., 1974).

By 1975, osprey populations had been studied at many locations and a review of research, management, and status of the osprey in North America was presented at the First World Birds of Prey Conference in Vienna, Austria (Henny, 1977). Declining populations and low productivity were apparent at many locations, but with an indication that productivity was improving. Later, Wiemeyer and others (1988) reported that 15 percent and 20 percent eggshell thinning of osprey eggs was associated with 4.2 and 8.7 ppm wet weight (ww) DDE, respectively. Lincer (1975) reported that no North American raptor population that exhibited 18 percent or more eggshell thinning was able to maintain a stable population. In later years, the percentage of eggs with greater than 4.2 and greater than 8 ppm DDE ww (the latter value more closely approximating 18 percent thinning) was used to evaluate DDE effects on osprey reproduction. Reproduction rate information (based on nests with one egg randomly collected and chemically analyzed) further supported these classifications of contaminant effects (Henny and others, 2004). Wiemeyer and others (1975) suspected that dieldrin may have increased the mortality rate of adult ospreys in Connecticut, and reported a lethal concentration in the brain of an adult male that died in 1967. Another adult osprey in South Carolina was believed to have been poisoned by dieldrin in 1970 (Wiemeyer and others, 1980). None of 29 dead ospreys evaluated (1964–73) died of DDE poisoning. The Connecticut population appeared to decline more rapidly (from 71 pairs in 1960 to 31 pairs in 1961) than reproductive failure alone would predict; however, this precipitous decline may be at least partly explained, as suggested by Henny and Ogden (1970), by catastrophic mortality associated with the occurrence of the worst hurricane in decades (Donna) in September 1960, during the osprey's fall migration.

By 1981, a nationwide osprey nesting population estimate resulted in a count of approximately 8,000 pairs (Henny, 1983). Another nationwide population estimate, made in 1994, showed a 77.5-percent increase (to about 14,200 pairs; Houghton and Ryman, 1997), and a similar survey in 2001 indicated an approximate 25-percent increase (about 16,000–19,000 pairs; Poole and others, 2002). The initial survey in northwestern Mexico in 1977 (810 pairs) was followed by others during 1992–93 (1,362 pairs) and 2006 (1,343 pairs) (Henny and others, 2008). The increase in osprey eggshell thickness following the 1972 ban of DDT in the United States was reported in a study with a large series of 238 eggs collected in the Pacific Northwest from 1973 to 2008 (fig. 2; Henny and others, 2010).

Many of the OC pesticide, polychlorinated biphenyl (PCB), dioxin, and furan concentrations in osprey eggs decreased by the end of the 20th century; the decrease in residues resulted in limited or no adverse effects on populations, except in a few localized areas (Henny and others, 2010). Thus, the osprey, now with large, widely distributed populations again (at lakes, rivers, bays, and estuaries), provides a means of evaluating emerging contaminants with limited potential for confounding effects from the "legacy" group of contaminants (the "old" OCs). Newer contaminants, such as polybrominated diphenyl ethers (PBDEs), are widely used as flame retardants in thermoplastics, textiles, polyurethane

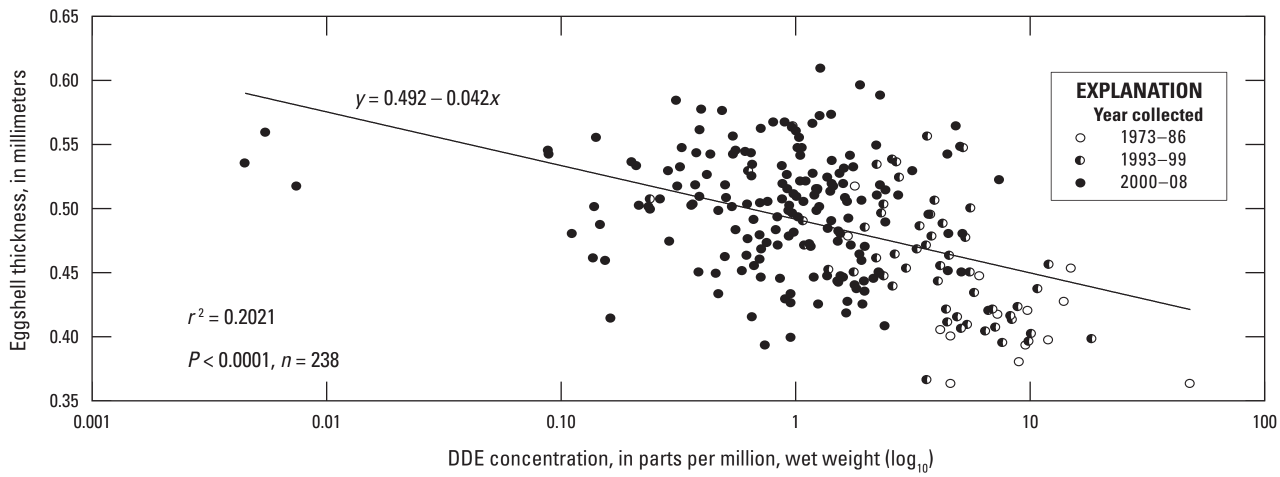

Figure 2. Semilogarithmic relation between dichlorodiphenyldichloroethylene (DDE) concentration in the egg and eggshell thickness in osprey eggs collected from the Pacific Northwest (Oregon, Washington, Idaho), 1972–2008. (Modified from Henny and others, 2010)

foams, and electronic circuitry. PBDEs have been reported in osprey eggs from Delaware, Maryland, Virginia, Oregon, and Washington (Rattner and others, 2004; Toschik and others, 2005; Henny and others, 2009a). In contrast to the legacy contaminants, PBDEs have increased in the biota since the 1970s, and, as concentrations increased above 1 ppm ww, there was some evidence of reduced osprey productivity (Henny and others, 2009a). More recently, wastewater-treatment-plant discharge, a known source of PBDEs (and also an indication of human population size at a location), was added to stream discharge (both converted to millions of gallons per day) in a novel approach (namely an approximate dilution index) to relate concentrations of waterborne contaminants to levels of these contaminants that reach osprey eggs (Henny and others, 2011). This simple approach improved understanding of the spatial patterns of the contaminants observed in osprey eggs. Other emerging contaminants found in osprey eggs since 2000 included perfluorinated acids and sulfonate compounds in the Eastern United States (Rattner and others, 2004; Toschik and others, 2005) and the chlorophenoxy herbicide DCPA (trade name Dacthal®) and the fungicide chlorothalonil in Puget Sound, WA (Chu and others, 2007). The osprey has played the role of a worldwide "sentinel species" for contaminant investigations. The species characteristics that make it so useful for this purpose were recently reviewed by Grove and others (2009).

Bald Eagle

Tissues from field-collected bald eagles and eggs were analyzed for pesticide residue content at Patuxent as part of the National Pesticide Monitoring Program; the first eagle carcass collected was obtained in 1960 (Coon and others, 1970). A limited number of carcasses were available for earlier years, but substantial numbers (692 carcasses) became available from 1966 to 1981 and routinely were analyzed for a series of contaminants; each report included a diagnosis for cause of death. Reports that included the raw data were published regularly by Patuxent scientists. A review of these Patuxent bald eagle data (see Peakall [1996], which includes diagnostic criteria developed at Patuxent) indicated that OC insecticides, especially the cyclodienes like dieldrin, killed eagles. The percentage of bald eagle deaths reported in the Patuxent literature and attributed to dieldrin poisoning decreased after 1970 (that is, 13 percent, 1966–70; 6.5 percent, 1971–74; 3.0 percent, 1975–77; and 1.7 percent, 1978–81). The use of dieldrin plus aldrin (which is metabolized to dieldrin) peaked in the United States in 1966 and 1967, and was banned by the U.S. Environmental Protection Agency for nearly all purposes in 1974 (Nisbet, 1988). Other causes of death from contaminants in bald eagles that were reported in papers published by Patuxent scientists and reviewed by Peakall (1996) included lead, thallium in poisoned bait, DDE and metabolites, and perhaps PCBs and endrin.

Because bald eagles are sensitive to human visits early in the nesting cycle, most bald eagle eggs were collected after the nest failed. This practice is in contrast to the random collection of fresh eggs from the osprey, which is more tolerant of human activity at its nest early in the nesting cycle. Bald eagle eggs were collected in 14 states from 1969 to 1979 (Wiemeyer and others, 1984) and 15 states from 1980 to 1984 (Wiemeyer and others, 1993). Bald eagle productivity appeared normal when eggs contained less than 3.6 ppm ww DDE, but decreased at higher concentrations. The largest series of eggs was collected in Wisconsin, Maine, Maryland, and Virginia; DDE residues declined substantially from 1969 to 1984 in all four states.

Uniqueness of the Patuxent Approach

Patuxent could conduct controlled laboratory studies, had a large chemistry section to measure contaminant levels, and had several field stations pursuing investigations throughout the United States; these characteristics resulted in a robust combined approach to studying contaminant issues and provided a critical number of personnel. The field stations often provided initial leads on which contaminants to test further in the laboratory. A good example in 1977 was Warbex (famphur), an OP, used on cattle as a pour-on for warble fly control. Black-billed magpies (*Pica pica*) in Oregon were reportedly dying nearby following a topical famphur application. The dead magpies were collected and frozen by an Oregon Department of Fish and Wildlife biologist in LaGrande, who also happened to be a raptor rehabilitator. During a weekend when he was gone, his wife ran out of food for the great horned owl (*Bubo virginianus*) they were rehabilitating. She found a magpie in the freezer and fed it to the owl. The owl immediately died. The story was relayed to me at the Pacific Northwest field station in Corvallis, OR, and a memo was sent to Patuxent. A laboratory study of common barn owls fed famphur-exposed quail showed significant cholinesterase (ChE) inhibition. Hill and Mendenhall (1980) concluded that owls could succumb to secondary OP poisoning. Then, in 1982, my colleagues and I conducted a field study that followed the recommended famphur pour-on treatment of 535 head of cattle at seven ranches in Washington (Henny and others, 1985). Famphur persisted on cow hair for more than 100 days, and magpies started dying on the day of treatment. A red-tailed hawk (*Buteo jamaicensis*) died 8 to 10 days after cattle treatment, and another was found sick 11 to 15 days after treatment (both had severe ChE inhibition); the dead hawk had eaten a magpie. From March 1984 to March 1985, other raptors were tested for famphur and fenthion poisoning at Patuxent. The list of deaths attributed to famphur or fenthion included nine bald eagles in four states, three red-tailed hawks in two states, and one great horned owl. The eagles and hawks had scavenged cattle carcasses or eaten magpies, European starlings (*Sturnus vulgaris*), or brown-headed cowbirds (*Molothrus ater*) (Franson and others, 1985; Henny and others, 1987). Before 1982, only two bald eagles had been checked at Patuxent for anti-ChE exposure (both negative), but many cases remained open (no cause of death determined).

Some Final Thoughts

The number of papers authored by Patuxent scientists from 1945 to 2010 dealing with raptors and contaminants (142 papers) and raptor population numbers and status (58 papers) peaked in the 1980s and declined rather dramatically in later years, after Patuxent lost many of its field stations following a 1993 reorganization of the USFWS. Publication of raptor contaminant studies at Patuxent started in the early 1960s; rapidly increased in the 1970s and 1980s, when the status and future of many raptor species were of great concern; then decreased in later years (fig. 3). Many field station personnel stayed in close contact with their Patuxent colleagues and shared information, although their publications were counted elsewhere. To address important issues, the Patuxent approach involved methods development, combining laboratory and field studies, using the scientific method/experimental approach (asking questions and formulating hypotheses),

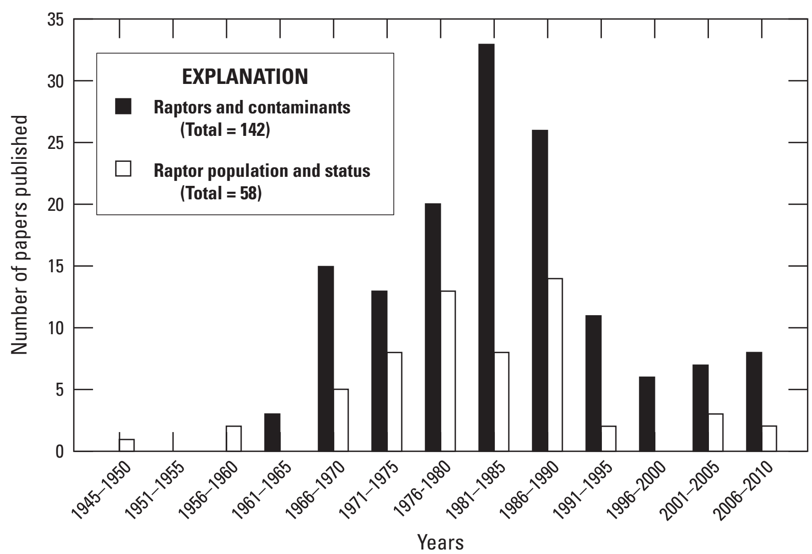

Figure 3. Summary of publications dealing with raptors and contaminants and raptor population and status, Patuxent Wildlife Research Center, Laurel, MD, 1945–2010.

developing forensic ecotoxicology approaches, and solving problems systematically. A unique combination of personnel was assembled to address important issues of the time. It was a joy to work with them and in the atmosphere at Patuxent during those critical years.

Acknowledgments

A list of all raptor publications originating from Patuxent Wildlife Research Center (Patuxent), with complete citations, is available from the Patuxent library, Laurel, MD (http://www.pwrc.usgs.gov/library/). Lynda J. Garrett, Patuxent librarian, graciously provided me with the list. I thank scientists Dan Anderson (University of California, Davis) and Gary H. Heinz (Patuxent), who made valuable comments on the first draft that improved the final document.

References Cited

Berger, D.D., Sindelar, C.R., Jr., and Gamble, K.E, 1969, The status of breeding peregrines in the eastern United States, *in* Hickey, J.J., ed., Peregrine falcon populations—Their biology and decline: Madison, WI, University of Wisconsin Press, p. 165–173.

Blus, L.J., 1984, DDE in birds' eggs—Comparisons of two methods for estimating critical levels: Wilson Bulletin, v. 96, no. 2, p. 268–276. [Also available at http://sora.unm.edu/node/130151.]

Broley, C.L., 1958, The plight of the American bald eagle: Audubon Magazine, v. 60, no. 4, p. 162–163.

Buckley, J.L., and DeWitt, J.B., 1963, 1963 progress report—Pesticide-eagle relationships, *in* A Florida notebook: Miami, FL, Proceedings of the National Audubon Society 59th Annual Convention, p. 15–20.

Cade, T.J., and Burnham, William, eds., 2003, Return of the peregrine—A North American saga of tenacity and teamwork: Boise, ID, The Peregrine Fund, 394 p.

Carson, R.L., 1962, Silent spring: Boston, MA, Houghton Mifflin Co., 368 p.

Chu, Shaogang, Henny, C.J., Kaiser, J.L., Drouillard, K.G., Haffner, G.H., and Letcher, R.J., 2007, Dacthal and chlorophenoxy herbicides and chlorothalonil fungicide in eggs of osprey (*Pandion haliaetus*) from the Duwamish-Lake Washington-Puget Sound area of Washington State, USA: Environmental Pollution, v. 145, no. 1, p. 374–381. [Also available at http://dx.doi.org/10.1016/j.envpol.2005.12.058.]

Coon, N.C., Locke, L.N., Cromartie, Eugene, and Reichel, W.L., 1970, Causes of bald eagle mortality, 1960–1965: Journal of Wildlife Diseases, v. 6, no. 1, p. 72–76. [Also available at http://dx.doi.org/10.7589/0090-3558-6.1.72.]

DeWitt, J.B., 1956, Toxicity of chlorinated insecticides to quail and pheasants: Atlantic Naturalist, v. 11, no. 3, p. 115–118.

DeWitt, J.B., and Buckley, J.L., 1962, Studies on pesticide-eagle relationships: Audubon Field Notes, v. 16, no. 6, p. 541.

Franson, J.C., Kolbe, E.J., and Carpenter, J.W., 1985, Famphur toxicosis in a bald eagle: Journal of Wildlife Diseases, v. 21, no. 3, p. 318–320. [Also available at http://dx.doi.org/10.7589/0090-3558-21.3.318.]

Grove, R.A., Henny, C.J., and Kaiser, J.L., 2009, Osprey—Worldwide sentinel species for assessing and monitoring environmental contamination in rivers, lakes, reservoirs and estuaries: Journal of Toxicological and Environmental Health, Part B, v. 12, no. 1, p. 25–44. [Also available at http://dx.doi.org/10.1080/10937400802545078.]

Henny, C.J., 1977, Research, management and status of the osprey in North America, *in* Chancellor, R.D., ed., Proceedings World Conference on Birds of Prey: Vienna, Austria, International Council for Bird Preservation, p. 199–222. [Also available at https://www.researchgate.net/publication/242505856_Research_management_and_status_of_the_Osprey_in_North_America_pp199-222.]

Henny, C.J., 1983, Distribution and abundance of nesting ospreys in the United States, *in* Bird, D.M., ed., Biology and management of bald eagles and ospreys: Ste. Anne de Bellevue, Quebec, Canada, Harpell Press, p. 175–186.

Henny, C.J., and Anderson, D.W., 1979, Osprey distribution, abundance and status in western North America—III. The Baja California and Gulf of California population: Bulletin of the Southern California Academy of Sciences, v. 78, no. 2, p. 89–106. [Also available at https://www.researchgate.net/publication/242464256_Osprey_distribution_abundance_and_status_in_western_North_America_III_The_Baja_California_and_Gulf_of_California_population.]

Henny, C.J., Anderson, D.W., Vera, A.C., and Cartron, J.L., 2008, Region-wide trends of nesting ospreys in northwestern Mexico—A three decade perspective: Journal of Raptor Research, v. 42, no. 4, p. 229–242. [Also available at http://fresc.usgs.gov/products/ProductDetails.aspx?ProductNumber=2039.]

Henny, C.J., Blus, L.J., Kolbe, E.J., and Fitzner, R.E., 1985, Organophosphate insecticide (famphur) topically applied to cattle kills magpies and hawks: Journal of Wildlife Management, v. 49, no. 3, p. 648–658. [Also available at http://dx.doi.org/10.2307/3801689.]

Henny, C.J., Blus, L.J., and Stafford, C.J., 1983, Effects of heptachlor on American kestrels in the Columbia Basin, Oregon: Journal of Wildlife Management, v. 47, no. 4, p. 1080–1087. [Also available at http://dx.doi.org/10.2307/3808167.]

Henny, C.J., Byrd, M.A., Jacobs, J.A., McLain, P.D., Todd, M.R., and Halla, B.F., 1977, Mid-Atlantic coast osprey population—Present numbers, productivity, pollutant contamination, and status: Journal of Wildlife Management, v. 41, no. 2, p. 254–265. [Also available at http://dx.doi.org/10.2307/3800602.]

Henny, C.J., Collins, C.A., and Deibert, W.J., 1978a, Osprey distribution, abundance, and status in western North America—II. The Oregon population: Murrelet, v. 59, no. 1, p. 14–25. [Also available at http://dx.doi.org/10.2307/3534722.]

Henny, C.J., Dunaway, D.J., Mallette, R.D., and Koplin, J.R., 1978b, Osprey distribution, abundance and status in western North America—I. The northern California population: Northwest Science, v. 52, no. 3, p. 261–271. [Also available at https://www.researchgate.net/publication/242484358_Osprey_distribution_abundance_and_status_in_western_North_America_I_The_northern_California_population.]

Henny, C.J., Grove, R.A., Kaiser, J.L., and Bentley, V.R., 2004, An evaluation of osprey eggs to determine spatial residue patterns and effects of contaminants along the lower Columbia River, U.S.A, *in* Chancellor, R.D., and Meyburg, B.-U., eds., Raptors worldwide: Hungary, Budapest, World Working Group Birds of Prey and MME/Hungarian BirdLife, p. 369–388. [Also available at http://fresc.usgs.gov/products/ProductDetails.aspx?ProductNumber=1268.]

Henny, C.J., Grove, R.A., Kaiser, J.L., and Johnson, B.L., 2010, North American osprey populations and contaminants—Historic and contemporary perspectives: Journal of Toxicological Environmental Health, part B, v. 13, no. 7–8, p. 579–603. [Also available at http://dx.doi.org/10.1080/10937404.2010.538658.]

Henny, C.J., Grove, R.A., Kaiser, J.L., Johnson, B.L., Furl, C.V., and Letcher, R.J., 2011, Wastewater dilution index partially explains observed polybrominated diphenyl ether flame retardant concentrations in osprey eggs from Columbia River Basin, 2008–2009: Ecotoxicology, v. 20, no. 4, p. 682–697. [Also available at http://dx.doi.org/10.1007/s10646-011-0608-2.]

Henny, C.J., Kaiser, J.L., Grove, R.A., Johnson, B.L., and Letcher, R.J., 2009a, Polybrominated diphenyl ether flame retardants in eggs may reduce reproductive success of ospreys in Oregon and Washington, USA: Ecotoxicology, v. 18, no. 7, p. 802–813. [Also available at http://dx.doi.org/10.1007/s10646-009-0323-4.]

Henny, C.J., Kolbe, E.J., Hill, E.F., and Blus, L.J., 1987, Case histories of bald eagles and other raptors killed by organophosphorus insecticides topically applied to livestock: Journal of Wildlife Diseases, v. 23, no. 2, p. 292–295. [Also available at http://dx.doi.org/10.7589/0090-3558-23.2.292.]

Henny, C.J., and Noltemeier, A.P., 1975, Osprey nesting populations in the coastal Carolinas: American Birds, v. 29, no. 6, p. 1073–1079. [Also available at https://sora.unm.edu/node/112542.]

Henny, C.J., and Ogden, J.C., 1970, Estimated status of osprey populations in the United States: Journal of Wildlife Management, v. 34, no. 1, p. 214–217. [Also available at http://dx.doi.org/10.2307/3799513.]

Henny, C.J., Overton, W.S., and Wight, H.M., 1970, Determining parameters for populations by using structural models: Journal of Wildlife Management, v. 34, no. 4, p. 690–703. [Also available at http://dx.doi.org/10.2307/3799133.]

Henny, C.J., Schmid, F.C., Martin, E.M., and Hood, L.L., 1973, Territorial behavior, pesticides, and the population ecology of red-shouldered hawks in central Maryland, 1943–1971: Ecology, v. 54, no. 3, p. 545–554. [Also available at http://dx.doi.org/10.2307/1935339.]

Henny, C.J., Smith, M.M., and Stotts, V.D., 1974, The 1973 distribution and abundance of breeding ospreys in the Chesapeake Bay: Chesapeake Science, v. 15, no. 3, p. 125–133. [Also available at http://www.jstor.org/stable/1351027.]

Henny, C.J., and Van Velzen, W.T., 1972, Migration patterns and wintering localities of American ospreys: Journal of Wildlife Management, v. 36, no. 4, p. 1133–1141. [Also available at http://dx.doi.org/10.2307/3799242.]

Henny, C.J., Ward, F.P., Riddle, K.E., and Prouty, R.M., 1982, Migratory peregrine falcons (*Falco peregrinus*) accumulate pesticides in Latin America during winter: Canadian Field-Naturalist, v. 96, no. 3, p. 333–338. [Also available at http://www.biodiversitylibrary.org/item/89040#page/353/mode/1up.]

Henny, C.J., and Wight, W.M., 1969, An endangered osprey population—Estimates of mortality and production: Auk, v. 86, p. 188–198. [Also available at https://sora.unm.edu/node/21848.]

Henny, C.J., Yates, M.A., and Seegar, W.S., 2009b, Dramatic declines of DDE and other organochlorines in spring migrant peregrine falcons from Padre Island, TX, 1978–2004: Journal of Raptor Research, v. 43, no. 1, p. 37–42. [Also available at http://fresc.usgs.gov/products/ProductDetails.aspx?ProductNumber=2090.]

Hickey, J.J., 1942, Eastern population of the duck hawk: Auk, v. 59, p. 176–204. [Also available at https://sora.unm.edu/node/18329.]

Hickey, J.J., 1952, Survival studies of banded birds: Washington, D.C., Special Scientific Report—Wildlife, no. 15, 177 p. [Also available at https://babel.hathitrust.org/cgi/pt?id=mdp.39015077581133;view=1up;seq=3.]

Hickey, J.J., ed., 1969, Peregrine falcon populations—Their biology and decline: Madison, WI, University of Wisconsin Press, 596 p.

Hickey, J.J., and Anderson, D.W., 1968, Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds: Science, v. 162, no. 3850, p. 271–273. [Also available at http://www.jstor.org/stable/1725067.]

Hill, E.F., and Mendenhall, V.M., 1980, Secondary poisoning of barn owls with famphur, an organophosphate insecticide: Journal of Wildlife Management, v. 44, no. 3, p. 676–681. [Also available at http://dx.doi.org/10.2307/3808017.]

Hotchkiss, Neil, and Pough, R.H., 1946, Effect on forest birds of DDT used for gypsy moth control in Pennsylvania: Journal of Wildlife Management, v. 10, no. 3, p. 202–207. [Also available at http://dx.doi.org/10.2307/3795833.]

Houghton, L.M., and Rymon, L.M., 1997, Nesting distribution and population status of U.S. ospreys, 1994: Journal of Raptor Research, v. 31, no. 1, p. 44–53. [Also available at https://sora.unm.edu/node/53582.]

Lincer, J.L., 1975, DDE-induced eggshell-thinning in the American kestrel—A comparison of the field situation and laboratory results: Journal of Applied Ecology, v. 12, no. 3, p. 781–793. [Also available at http://dx.doi.org/10.2307/2402090.]

Martin, E.M., 2004, Decreases in a population of red-shouldered hawks nesting in central Maryland: Journal of Raptor Research, v. 38, no. 4, p. 312–319. [Also available at https://sora.unm.edu/node/54130.]

Mitchell, R.T., Blagbrough, H.P., and Van Etten, R.C., 1953, The effects of DDT upon the survival and growth of nestling songbirds: Journal of Wildlife Management, v. 17, no. 1, p. 45–54. [Also available at http://dx.doi.org/10.2307/3796804.]

Nisbet, I.C.T., 1988, The relative importance of DDE and dieldrin in the decline of peregrine falcon populations, *in* Cade, T.J., Enderson, J.H., Thelander, C.G., and White, C.M., eds., Peregrine falcon populations—Their management and recovery: Boise, ID, The Peregrine Fund, Inc., p. 351–375.

Peakall, D.B., 1996, Dieldrin and other cyclodiene pesticides in wildlife, *in* Beyer, W.N., Heinz, G.H., and Redmon-Norwood, A.W., eds., Environmental contaminants in wildlife—Interpreting tissue concentrations: Boca Raton, FL, Lewis Publishers, p. 73–97.

Peterson, R.T., 1969, Population trends of ospreys in the northeastern United States, *in* Hickey, J.J., ed., Peregrine falcon populations—Their biology and decline: Madison, WI, University of Wisconsin Press, p. 333–337.

Poole, A.F., Bierregaard, R.O., and Martell, M.S., 2002, Osprey (*Pandion haliaetus*), *in* Poole, A.F., and Gill, Frank, eds., The Birds of North America, issue no. 683: Philadelphia, PA, Birds of North America, Inc.

Porter, R.D., and Wiemeyer, S.N., 1969, Dieldrin and DDT—Effects on sparrow hawk eggshells and reproduction: Science, v. 165, no. 3889, p. 199–200. [Also available at http://www.jstor.org/stable/1726452.]

Postupalsky, Sergej, 1969, The status of the osprey in Michigan in 1965, *in* Hickey, J.J., ed., Peregrine falcon populations—Their biology and decline: Madison, WI, University of Wisconsin Press, p. 338–340.

Ratcliffe, D.A., 1967, Decrease in eggshell weight in certain birds of prey: Nature, v. 215, no. 5097, p. 208–210. [Also available at http://dx.doi.org/10.1038/215208a0.]

Ratcliffe, D.A., 1969, Population trends of the peregrine falcon in Great Britain, *in* Hickey, J.J., ed., Peregrine falcon populations—Their biology and decline: Madison, WI, University of Wisconsin Press, p. 239–269.

Rattner, B.A., McGowan, P.C., Golden, N.H., Hatfield, J.S., Toschik, P.C., Lukei, R.F., Jr., Hale, R.C., Schmitz-Alfonso, Isabelle, and Rice, C.P., 2004, Contaminant exposure and reproductive success of ospreys (*Pandion haliaetus*) nesting in Chesapeake Bay regions of concern: Archives of Environmental Contaminants and Toxicology, v. 47, no. 1, p. 126–140. [Also available at http://dx.doi.org/10.1007/s00244-003-3160-0.]

Robbins, C.S., 1950, Hawks over Maryland, fall of 1949: Maryland Birdlife, v. 6, no. 1, p. 2–11. [Also available at https://sora.unm.edu/node/132726.]

Robbins, C.S., 1956, Hawk watch: Atlantic Naturalist, v. 11, no. 5, p. 208–217.

Robbins, C.S., 1960, Status of the bald eagle, summer of 1959: Washington, D.C., U.S. Fish and Wildlife Service, Wildlife Leaflet 418, 8 p. [Also available at https://archive.org/details/statusofbaldeagl418robb.]

Robbins, C.S., Springer, P.F., and Webster, C.G., 1951, Effects of five-year DDT application on breeding bird population: Journal of Wildlife Management, v. 15, no. 2, p. 213–216. [Also available at http://dx.doi.org/10.2307/3796613.]

Robbins, C.S., and Stewart, R.E., 1949, Effects of DDT on bird population of scrub forest: Journal of Wildlife Management, v. 13, no. 1, p. 11–16. [Also available at http://dx.doi.org/10.2307/3796121.]

Rudd, R.L., 1964, Pesticides and the living landscape: Madison, WI, University of Wisconsin Press, 320 p.

Schmid, F.C., 1966, The status of the osprey in Cape May County, New Jersey, between 1939 and 1963: Chesapeake Science, v. 7, no. 4, p. 220–223. [Also available at http://www.jstor.org/stable/1350442.]

Spitzer, P.L., Poole, A.F., and Scheibel, M.S., 1983, Initial recovery of breeding ospreys in the region between New York City and Boston, *in* Bird, D.M., ed., Biology and management of bald eagles and ospreys: Ste. Anne de Bellevue, Quebec, Canada, Harpell Press, p. 231–241.

Stewart, R.E., 1949, Ecology of a nesting red-shouldered hawk population: Wilson Bulletin, v. 61, no. 1, p. 26–35. [Also available at http://sora.unm.edu/node/126881.]

Stewart, R.E., Cope, J.B., and Robbins, C.S., 1945, Live trapping of hawks and owls: Journal of Wildlife Management, v. 9, no. 2, p. 99–104. [Also available at http://dx.doi.org/10.2307/3795888.]

Stewart, R.E., Cope, J.B., Robbins, C.S., and Brainerd, J.W., 1946, Effects of DDT on birds at Patuxent Wildlife Research Refuge: Journal of Wildlife Management, v. 10, no. 3, p. 195–201. [Also available at http://dx.doi.org/10.2307/3795832.]

Stickel, L.F., Chura, N.J., Stewart, P.A., Menzie, C.M., Prouty, R.M., and Reichel, W.L., 1966, Bald eagle pesticide relations: Transactions of the North American Wildlife and Natural Resources Conference, v. 31, p. 190–200.

Stickel, L.F., Schmid, F.C., Reichel, W.L., and Ames, P.L., 1965, Ospreys in Connecticut and Maryland: Washington, D.C., U.S. Fish and Wildlife Service, Circular 226, p. 4–6.

Stickel, W.H., Stickel, L.F., and Coon, F.B., 1970, DDE and DDD residues correlated with mortality in experimental birds, *in* Deichmann, W.B., ed., Pesticides symposia—Seventh Inter-American Conference on Toxicology and Occupational Medicine: Miami, FL, Helios and Associates, p. 287–294.

Stickel, W.H., Stickel, L.F., and Spann, J.W., 1969, Tissue residues of dieldrin in relation to mortality in birds and mammals, *in* Miller, M.W., and Berg, G.G., eds. Chemical fallout—Current research on persistent pesticides: Springfield, IL, Charles C. Thomas, p. 174–204.

Stickel, L.F., Wiemeyer, S.N., and Blus, L.J., 1973, Pesticide residues in eggs of wild birds—Adjustment for loss of moisture and lipid: Bulletin of Environmental Contamination and Toxicology, v. 9, no. 4, p. 193–196. [Also available at http://dx.doi.org/10.1007/BF01684824.]

Toschik, P.C., Rattner, B.A., McGowan, P.C., Christman, M.C., Carter, D.B., Hale, R.C., Matson, C.W., and Ottinger, M.A., 2005, Effects of contaminant exposure on reproductive success of ospreys (*Pandion haliaetus*) nesting in Delaware River and Bay, USA: Environmental Toxicology and Chemistry, v. 24, no. 3, p. 617–628. [Also available at http://dx.doi.org/10.1897/04-141R.1.]

Wiemeyer, S.N., Bunck, C.M., and Krynitsky, A.J., 1988, Organochlorine pesticides, polychlorinated biphenyls and mercury in osprey eggs—1970–1979—and their relationships to shell thinning and productivity: Archives of Environmental Contamination and Toxicology, v. 17, no. 6, p. 767–787. [Also available at http://dx.doi.org/10.1007/BF01061982.]

Wiemeyer, S.N., Bunck, C.M., and Stafford, C.J., 1993, Environmental contaminants in bald eagle eggs—1980–84—and further interpretations of relationships to productivity and shell thickness: Archives of Environmental Contamination and Toxicology, v. 24, no. 2, p. 213–227. [Also available at http://dx.doi.org/10.1007/BF01141351.]

Wiemeyer, S.N., Lamont, T.G., Bunck, C.M., Sindelar, C.R., Gramlich, F.J., Fraser, J.D., and Byrd, M.A., 1984, Organochlorine pesticide, polychlorobiphenyl and mercury residues in bald eagle eggs—1969–79—and their relationships to shell thinning and reproduction: Archives of Environmental Contamination and Toxicology, v. 13, no. 5, p. 529–549. [Also available at http://dx.doi.org/10.1007/BF01056332.]

Wiemeyer, S.N., Lamont, T.G., and Locke, L.N., 1980, Residues of environmental pollutants and necropsy data for eastern United States ospreys, 1964–1973: Estuaries, v. 3, no. 3, p. 155–167. [Also available at http://www.jstor.org/stable/1352065.]

Wiemeyer, S.N., and Porter, R.D., 1970, DDE thins eggshells of captive American kestrels: Nature, v. 227, no. 5259, p. 737–738. [Also available at http://dx.doi.org/10.1038/227737a0.]

Wiemeyer, S.N., Porter, R.D., Hensler, G.L., and Maistrelli, J.R., 1986, DDE, DDT + dieldrin—Residues in American kestrels and relations to reproduction: Washington, D.C., U.S. Fish and Wildlife Service, Fish and Wildlife Technical Report 6, 33 p.

Wiemeyer, S.N., Spitzer, P.R., Krantz, W.C., Lamont, T.G., and Cromartie, Eugene, 1975, Effects of environmental pollutants on Connecticut and Maryland ospreys: Journal of Wildlife Management, v. 39, no. 1, p. 124–139. [Also available at http://dx.doi.org/10.2307/3800475.]

Research on Amphibians and Reptiles at Patuxent: A Synopsis

By Donald W. Sparling

Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, has a long history of research on amphibians and reptiles, beginning long before such research became commonplace. A survey of the Patuxent bibliography revealed 385 papers, books, or book chapters written or cowritten by Patuxent scientists from 1942 to 2015. Patuxent scientists are authors on 231 publications on amphibians, 226 publications on reptiles, and 36 publications that included both classes.

These papers cover a wide range of topics, including contaminants, systematics, general ecology, sampling techniques, and disease (fig. 1). Notably, papers on amphibians and reptiles are nearly equal in number, in contrast to the literature as a whole, where papers on amphibians far outnumber papers on reptiles.

The oldest paper in the Patuxent bibliography on herpetofauna was published by biologist William Stickel in 1942 (Stickel, 1942). Bill's wildlife career at Patuxent in the early 1940s was only partially interrupted when he was drafted into the Army during World War II. While in New Guinea and the Philippines, he found time to pursue his biological interests. He collected a variety of specimens, several of which were later found to be new to science. A species of lizard (*Sphenomorphus stickeli*) from New Guinea (Loveridge, 1948) and a frog (*Kaloula stickeli*) from the Philippines (Inger, 1954) were named in his honor (Stickel, 1996; Perry, 2007, p. 259). Patuxent biologist Francis Uhler was also active in providing information about snakes in the 1940s (Uhler, 1944). Uhler also conducted a food habits study with snakes in the George Washington National Forest in Virginia just prior to coming to Patuxent (Uhler and others, 1939).

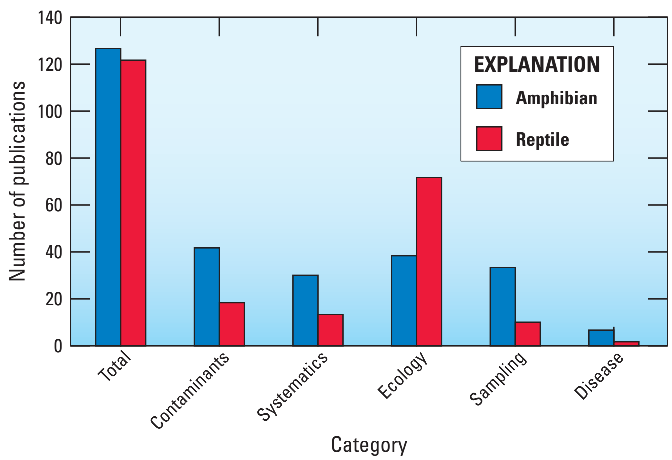

Figure 1. Number of publications on amphibians and reptiles authored by Patuxent Wildlife Research Center scientists, 1942–2011, by category.

Mr. Stickel and his wife, Dr. Lucille Stickel, were prolific writers in the 1940s and 1950s. Dr. Stickel published several papers on the ecology and movements of eastern box turtles (*Terrapene carolina*), and all of her research was done at Patuxent (Stickel, 1950, 1978). Her study on box turtles was continued for approximately 60 years by several biologists and is a highly cited classic (Hall and others, 1999). Patuxent biologist Paula Henry did the most recent field work on this subject, and published reviews of the work in 2003 (Henry, 2003).

Research on herpetofauna was at a low during the 1960s and 1970s, but increased dramatically during the 1980s, primarily because of the work of three Patuxent scientists, Thomas H. Fritts, Russell J. Hall, and Robert P. Reynolds. Tom Fritts was a herpetologist at the Museum of Natural History, Washington, D.C., one of the field stations of Patuxent. He and Gordon Rodda wrote extensively on the invasive brown tree snake (*Boiga irregularis*), its effects on native populations of birds on Guam, and its threat to other Pacific Islands (Fritts, 1988; Rodda and others, 1991). Fritts also studied sea turtles and published papers on their distribution, ecology, and exposure to contaminants (Fritts, 1981).

Russ Hall was a major contributor of herpetofauna research during the 1980s, and an early pioneer in the area of amphibian and reptile ecotoxicology. Studies were published on the effects and uptake of pesticides, polychlorobiphenyls (PCBs), metals, polycyclic aromatic hydrocarbons (PAHs), and organochlorines on anurans (frogs and toads), salamanders, lizards, sea turtles, and other reptiles (Hall, 1988; Hall and Coon, 1988; Hall and Henry, 1992). Another contaminant study on herpetofauna was conducted by Peter Albers, who studied survival of spotted salamander (*Ambystoma maculatum*) eggs in temporary woodland ponds (Albers and Prouty,

1987) and contaminants in snapping turtles (*Chelydra serpentina*) in a tidal wetland (Albers and others, 1986). Patuxent researcher Gary H. Heinz studied contaminant levels in alligators (*Alligator mississippiensis*) in Florida (Heinz and others, 1991) and in snakes in Lake Michigan (Heinz and others, 1980).

During the 1990s, the National Biological Survey (later the National Biological Service) (NBS) was formed from research entities within the U.S. Department of the Interior (DOI), and vertebrate biologists from the National Museum of Natural History of the Smithsonian Institution joined the Patuxent staff. This collaboration resulted in an extensive series of publications on the distribution and systematics of amphibians and reptiles under the Patuxent banner. Patuxent researcher Roy McDiarmid published three books on tadpoles in collaboration with Ronald Altig (McDiarmid and Altig, 1999; Altig and McDiarmid, 2015; Altig and others, 1998). McDiarmid also published several descriptions of amphibian taxa as peer-reviewed articles or book chapters, and with other Patuxent scientists published the widely used references for the inventory and monitoring of amphibian (Heyer and others, 1994) and reptile (McDiarmid and others, 2012) biodiversity. As a coauthor with colleagues, McDiarmid also wrote a monograph on the history of herpetologists and herpetology in the DOI (Lovich and others, 2012).

A colleague of McDiarmid, Bob Reynolds, station leader of the Patuxent Biological Survey Unit at the National Museum of Natural History, conducted surveys of amphibians and reptiles throughout northern South America in Bolivia, Ecuador, Guyana, and Peru. In 2005, he collaborated with Tom Hollowell on a checklist of the terrestrial vertebrates of the Guyana Shield (Hollowell and Reynolds, 2005); more recently, he collaborated on a monograph on the amphibians and reptiles of Guyana (Cole and others, 2013). In addition, he published a number of regional herpetological surveys throughout Guyana (MacCulloch and others, 2007; MacCulloch and Reynolds, 2012; Reynolds and MacCulloch, 2012; MacCulloch and Reynolds, 2013). Reynolds also published peer-reviewed descriptions of new species for four amphibians and three snakes (Reynolds and Foster, 1992; Wynn and others, 2012).

Patuxent biologist Matthew Perry monitored amphibians and reptiles with pitfall and funnel traps set along drift fences on mitigated forested wetlands (fig. 2). These studies revealed that the wood frog (*Rana sylvatica*) was the only amphibian species found in reference forested wetlands, but not in adjacent mitigated sites (Perry and others, 1996, 2001). Perry also monitored amphibians and reptiles to evaluate five habitat management practices on a powerline right-of-way (Perry and others, 1997).

Figure 2. Pitfall and funnel traps along drift fence to capture amphibians and reptiles sampled by Brian Eyler, U.S. Geological Survey, as part of forested wetland mitigation study, 1996. Photo by Matthew C. Perry, U.S. Geological Survey.

During the 2000s, research, especially on amphibians, expanded into multiple areas because of the publication of papers resulting from the U.S. Geological Survey (USGS) Amphibian Research and Monitoring Initiative (ARMI), the Patuxent North American Amphibian Monitoring Program (NAAMP), and other ongoing studies. The ARMI was started in 2000, after the NBS became part of the U.S. Geological Survey (Muths and others, 2005). Its mission was to monitor amphibian populations and investigate probable causes of amphibian declines (Corn and others, 2005). Robin Jung, the first Northeast ARMI coordinator, collaborated with biostatisticians at Patuxent to improve methods of surveying and sampling amphibians. Patuxent biologists Larissa Bailey and Evan Grant subsequently led the Northeast ARMI program at Patuxent. Some examples of ARMI research include vernal pool egg mass counts and the study of potential climate change effects on the endangered Shenandoah salamanders (*Plethodon shenandoah*) in Virginia (Jung and others, 2005).

The NAAMP, initiated by Patuxent biologist Sam Droege, later was led by Patuxent biologist Linda Weir, who was followed by Evan Grant. It is a large-scale monitoring program consisting of more than 500 volunteers in more than 20 states collecting data to assess frog population trends (Weir and Mossman, 2005). This book chapter by Weir and Mossman describes the NAAMP protocol and partnership. Droege was also instrumental in developing Frogwatch USA, a citizen-based science program for people to monitor their backyard pond or neighborhood wetland. The program was transferred to the National Wildlife Federation and is now (2016) coordinated by the Association of Zoos and Aquariums (accessed May 21, 2015, at https://www.aza.org/frogwatch/). Additional key USGS scientists in this area included Jim Hines, Bill Kendall, Jim Nichols, Andy Royle, and John Sauer (MacKenzie and others, 2002).

Investigations on contaminants continued during the 2000s with my work, which focused on effects of pesticides on amphibians in the Sierra Nevada of California, and the effects of variety of pesticides, acidification, metals, perchlorate, and sediment-borne lead on amphibians (Sparling and others, 2000; Linder and others, 2003a; Linder and others, 2003b). Patuxent biologist Mark Melancon focused on biomarkers. Patuxent scientists J. Michael Meyers, Jeff Hatfield, Robin Jung, Priya Nanjappa, and Jerry Longcore studied the conservation of amphibians and reptiles (Hatfield and others, 2004; Whiting and others, 2004, Jung and others, 2005). Longcore and others (2006) surveyed anurans in the northeastern United States to determine the distribution of chytridiomycosis, a lethal disease in some species of amphibians.

Productivity at Patuxent in terms of publications on amphibians and reptiles has generally increased since the 1950s (fig. 3) and continues to increase. Approximately 20 new papers were published during the first 18 months of 2010–11; at that rate, more than 125 papers would be published during the decade from 2010–19. The collaborators on these projects number more than 100, and contributions have been received from colleagues from all over the United States and several foreign countries.

Major Contributions of Research by Patuxent Scientists

Over the years, research on amphibians and reptiles has focused on natural history, contaminants, systematics, sampling methodology, distribution, and conservation. Major contributions of Patuxent scientists to research on amphibians and reptiles include—

- New and improved methodologies to survey and accurately estimate the size of amphibian and reptile populations;

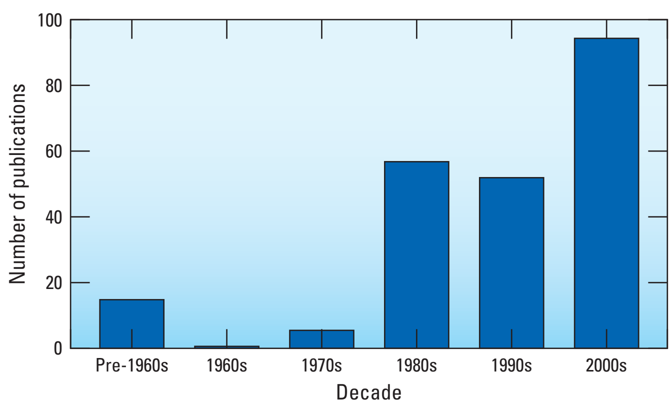

Figure 3. Number of publications on amphibians and reptiles published by Patuxent Wildlife Research Center scientists, by decade.

- Information on the accumulation and effects of many environmental contaminants, including mercury, organophosphate pesticides, lead, perchlorate, ammonium, toxaphene, endrin, PCBs, and methoxychlor, as well as multiple stressors, on amphibians;
- Increased knowledge about the effects of PAHs, dicofol, dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE), organochlorines, aldrin, petroleum, organophosphate pesticides, and mercury on reptiles;
- North American Amphibian Monitoring Program, developed by using the Breeding Bird Survey as a model;
- Information on the ecology, distribution, and conservation needs of many species of amphibians and reptiles;
- Early warning about and studies of the invasive brown tree snake before and during its devastation of avifauna on Guam;
- Input to and guidance on the formation of the Amphibian Research and Monitoring Initiative;
- Important research and conservation guidelines for endangered sea turtles;
- Assistance in the creation of Frogwatch USA, a citizen-based program to monitor amphibians; and
- A more than 60-year-long investigation of the population dynamics of eastern box turtles, one of the longest studies ever conducted on a single species.

Selected References

Albers, P.H., and Prouty, R.M., 1987, Survival of spotted salamander eggs in temporary woodland ponds of coastal Maryland: Environmental Pollution, v. 46, no. 1, p. 45–61. [Also available at http://dx.doi.org/10.1016/0269-7491(87)90144-8.]

Albers, P.H., Sileo, Louis, and Mulhern, B.M., 1986, Effects of environmental contaminants on snapping turtles of a tidal wetland: Archives of Environmental Contamination and Toxicology, v. 15, no. 1, p. 39–49. [Also available at http://dx.doi.org/10.1007/BF01055247.]

Altig, Ronald, and McDiarmid, R.W., 2015, Handbook of larval amphibians of the United States and Canada: Ithaca, NY, Cornell University Press, 345 p.

Altig, Ronald, McDiarmid, R.W., Nichols, K.A., and Ustach, P.C., 1998, A key to the anuran tadpoles of the United States and Canada: Contemporary Herpetology Information Series 2, p. 1–58.

Cole, C.J., Townsend, C.R., Reynolds, R.P., MacCulloch, R.A., and Lathrop, Amy, 2013, Amphibians and reptiles of Guyana, South America—Illustrated keys, annotated species accounts, and a biogeographic synopsis: Proceedings of the Biological Society of Washington, v. 125, no. 4, p. 317–620. [Also available at http://dx.doi.org/10.2988/0006-324X-125.4.317.]

Corn, P.S., Adams, M.J., Battaglin, W.A., Gallant, A.L., James, D.L., Knutson, Melinda, Langtimm, C.A., and Sauer, J.R., 2005, Amphibian Research and Monitoring Initiative—Concepts and implementation: U.S. Geological Survey Scientific Investigations Report 2005–5015, 23 p. [Also available at https://pubs.er.usgs.gov/publication/5230279.]

Fritts, T.H., 1981, Marine turtles of the Galápagos Islands and adjacent areas of the eastern Pacific on the basis of observations made by J.R. Slevin 1905–1906: Journal of Herpetology, v. 15, no. 3, p. 293–301. [Also available at http://dx.doi.org/10.2307/1563432.]

Fritts, T.H., 1988, The brown tree snake, *Boiga irregularis*, a threat to Pacific Islands: Washington, D.C., U.S. Fish and Wildlife Service Biological Report, v. 88, no. 31, 36 p. [Also available at https://babel.hathitrust.org/cgi/pt?id=mdp.39015086474775;view=1up;seq=3.]

Hall, R.J., 1994, Herpetofaunal diversity of the Four Holes Swamp, South Carolina: Washington, D.C., National Biological Survey, Resource Publication 198, 45 p. [Also available at http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA322610.]

Hall, R.J., and Coon, N.C., 1988, Interpreting residues of petroleum hydrocarbons in wildlife tissues: Washington, D.C., U.S. Fish and Wildlife Service, Biological Report 88, 15 p. [Also available at http://www.pwrc.usgs.gov/oilinla/pdfs/3610_Hall.pdf.]

Hall, R.J., and Henry, P.F.P., 1992, Assessing effects of pesticides on amphibians and reptiles—Status and needs: Herpetological Journal, v. 2, p. 65–71. [Also available at https://www.researchgate.net/publication/263008772_Assessing_effects_of_pesticides_on_amphibians_and_reptiles_status_and_needs_Herpetol_J_2365-71.]

Hall, R.J., Henry, P.F.P., and Bunck, C.M., 1999, Fifty-year trends in a box turtle population in Maryland: Biological Conservation, v. 88, no. 2, p. 165–172. [Also available at http://dx.doi.org/10.1016/S0006-3207(98)00107-4.]

Hatfield, J.S., Price, A.H., Diamond, D.D., and True, C.D., 2004, Houston toad (*Bufo houstonensis*) in Bastrop County, Texas—Need for protecting multiple subpopulations, *in* Akçakaya, H.R., Burgman, M.A., Kindvall, Oskar, Wood, C.C., Sjögren-Gulve, Per, Hatfield, J.S., and McCarthy, M.A., eds., Species conservation and management—Case studies: Oxford, England, Oxford University Press, p. 292–298.

Heinz, G.H., Haseltine, S.D., Hall, R.J., and Krynitsky, A.J., 1980, Organochlorine and mercury residues in snakes from Pilot and Spider Islands, Lake Michigan—1978: Bulletin of Environmental Contamination and Toxicology, v. 25, no. 5, p. 738–743. [Also available at http://dx.doi.org/10.1007/BF01985601.]

Heinz, G.H., Percival, H.F., and Jennings, M.L., 1991, Contaminants in American alligator eggs from Lake Apopka, Lake Griffin, and Lake Okeechobee, Florida: Environmental Monitoring and Assessment, v. 16, no. 3, p. 277–285. [Also available at http://dx.doi.org/10.1007/BF00397615.]

Henry, P.F.P., 2003, The eastern box turtle at the Patuxent Wildlife Research Center 1940s to the present—Another view: Experimental Gerontology, v. 38, no. 7, p. 773–776. [Also available at http://dx.doi.org/10.1016/S0531-5565(03)00107-4.]

Heyer, W.R., Donnelly, M.A., McDiarmid, R.W., Hayek, L.C., and Foster, M.S., eds., 1994, Measuring and monitoring biological diversity—Standard methods for amphibians: Washington, D.C., Smithsonian Institution Press, 384 p.

Hollowell, Tom, and Reynolds, R.P., eds., 2005, Checklist of the terrestrial vertebrates of the Guiana Shield: Bulletin of the Biological Society of Washington, no. 13, 106 p. [Also available at http://www.pwrc.usgs.gov/prodabs/ab04060906/6484_Hollowell.pdf.]

Inger, R.F., 1954, Systematics and zoogeography of Philippine Amphibia: Fieldiana Zoology, v. 33, no. 4, p. 183–531. [Also available at https://archive.org/details/systematicszooge334inge.]

Jung, R.E., Royle, J.A., Sauer, J.R., Addison, C., Rau, R.D., Shirk, J.L., and Whissel, J.C., 2005, Estimation of stream salamander (Plethodontidae, Desmognathinae, and Plethodontinae) populations in Shenandoah National Park, Virginia, USA: Alytes, v. 22, no. 3–4, p. 72–84.

Linder, Greg, Krest, S.K., and Sparling, D.W., eds., 2003a, Amphibian decline—An integrated analysis of multiple stressor effects: Pensacola, FL, Society of Environmental Toxicology and Chemistry, 368 p.

Linder, Greg, Krest, S.K., Sparling, D.W., and Little, E.E., eds., 2003b, Multiple stressor effects in relation to declining amphibian populations: West Conshohocken, PA, American Society for Testing and Materials International, Selected Technical Paper 1443, 282 p. [Also available at http://www.astm.org/DIGITAL_LIBRARY/STP/SOURCE_PAGES/STP1443.htm.]

Longcore, J.R., Longcore, J.E., Pessier, A.P., and Halteman, W.A., 2007, Chytridiomycosis widespread in anurans of northeastern United States: Journal of Wildlife Management, v. 71, no. 2, p. 435–444. [Also available at http://www.jstor.org/stable/4495202.]

Loveridge, Arthur, 1948, New Guinean reptiles and amphibians in the Museum of Comparative Zoölogy and United States National Museum: Bulletin of the Museum of Comparative Zoology, v. 101, no. 2, p. 305–430. [Also available at http://biostor.org/reference/49254.]

Lovich, J.E., Scott, N.J., Jr., Bury, R.B., Dodd, C.K., Jr., and McDiarmid, R.W., 2012, A history of herpetologists and herpetology in the U.S. Department of the Interior: Herpetological Conservation and Biology, v. 7, Monograph 2, p. 1–45. [Also available at http://herpconbio.org/Volume_7/Monographs/Lovich_etal_2012.pdf.]

MacCulloch, R.D., Lathrop, Amy, Reynolds, R.P., Señaris, J.C., and Schneider, G.E., 2007, Herpetofauna of Mount Roraima, Guiana Shield region, northeastern South America: Herpetological Review, v. 38, no. 1, p. 24–30. [Also available at https://www.pwrc.usgs.gov/prodabs/reynolds/6735_macculloch.pdf.]

MacCulloch, R.D., and Reynolds, R.P., 2012, Amphibians and reptiles from Paramakatoi and Kato, Guyana: Check List, v. 8, no. 2, p. 207–210. [Also available at http://www.checklist.org.br/getpdf?SL004-12.]

MacCulloch, R.D., and Reynolds, R.P., 2013, Baseline inventory of amphibians and reptiles in the vicinity of Kurupukari, Guyana: Check List, v. 9, no. 6, p. 1378–1382. [Also available at http://www.checklist.org.br/getpdf?SL091-12.]

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, Sam, Royle, J.A., and Langtimm, C.A., 2002, Estimating site occupancy when detection probabilities are less than one: Ecology, v. 83, no. 8, p. 2248–2255. [Also available at http://dx.doi.org/10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2.]

McDiarmid, R.W., and Altig, Ronald, eds., 1999, Tadpoles—The biology of anuran larvae: Chicago, IL, University of Chicago Press, 458 p.

McDiarmid, R.W., Foster, M.S., Guyer, C., Gibbons, J.W., and Chernoff, N., eds., 2012, Reptile biodiversity—Standard methods for inventory and monitoring: Berkeley, CA, University of California Press, 412 p.

Muths, Erin, Jung, R.E., Bailey, L.L., Adams, M.J., Corn, P.S., Dodd, C.K., Jr., Fellers, G.M., Sadinski, W.J., Schwalbe, C.R., Walls, S.C., Fisher, R.N., Gallant, A.L., Battaglin, W.A., and Green, W.A., 2005, Amphibian Research and Monitoring Initiative (ARMI)—A successful start to a national program in the United States: Applied Herpetology, v. 2, no. 4, p. 355–371. [Also available at http://www.werc.usgs.gov/fileHandler.ashx?File=/Lists/Products/Attachments/3351/ARMI%20program.pdf.]

Perry, M.C., ed., 2007, The Washington Biologists' Field Club—Its members and its history (1900–2006): Washington, D.C., Washington Biologists' Field Club, 342 p. [Also available at http://www.pwrc.usgs.gov/resshow/perry/bios/wbfc_booksm.pdf.]

Perry, M.C., Osenton, P.C., Fallon, F.W., and Fallon, J.E., 1997, Optimal management strategies for biodiversity within a powerline right-of-way, *in* Williams, J.R., Goodrich-Mahoney, J.W., Wisniewski, J.R., and Wisniewski, Joe, eds., Sixth International Symposium on Environmental Concerns in Right-of-Way Management: New York, Elsevier Science, p. 133–139. [Also available at https://www.researchgate.net/publication/283296233_Optimal_management_strategies_for_biodiversity_within_a_powerline_right-of-way.]

Perry, M.C., Osenton, P.C., and Stoll, C.S., 2001, Biological diversity of created forested wetlands in comparison to reference forested wetlands in the Bay watershed, *in* Therres, G.D., ed., Conservation of biological diversity—A key to the restoration of Chesapeake Bay ecosystem and beyond: Annapolis, MD, Maryland Department of Natural Resources, p. 261–268. [Also available at http://ecos.fws.gov/ServCatFiles/reference/holding/45966.]

Perry, M.C., Sibrel, C.B., and Gough, G.A., 1996, Wetlands mitigation—Partnership between an electric power company and a federal wildlife refuge: Environmental Management, v. 20, no. 6, p. 933–939. [Also available at https://www.researchgate.net/publication/225222349_Wetlands_mitigation_Partnership_between_an_electric_power_company_and_a_federal_wildlife_refuge.]

Reynolds, R.P., and Foster, M.S., 1992, Four new species of frogs and one new species of snake from the Chapare region of Bolivia, with notes on other species: Herpetological Monographs, v. 6, p. 83–104. [Also available at http://dx.doi.org/10.2307/1466963.]

Reynolds, R.P., and MacCulloch, R.D., 2012, Preliminary checklist of the amphibians and reptiles of Baramita, Guyana: Check List, v. 8, no. 2, p. 211–214. [Also available at http://www.checklist.org.br/getpdf?SL003-12.]

Rodda, G.H., Fritts, T.H., and Reichel, J., 1991, The distributional patterns of reptiles and amphibians in the Mariana Islands: Micronesica, v. 24, no. 2, p. 195–210. [Also available at https://issuu.com/marc_virtual_library/docs/the_distributionl_patterns_of_repti/1.]

Sparling, D.W., Linder, Greg, and Bishop, C.A., eds., 2000, Ecotoxicology of amphibians and reptiles: Pensacola, FL, Society of Environmental Toxicology and Chemistry, SETAC Technical Publications Series, 617 p.

Stickel, L.F., 1950, Populations and home range relationships of the box turtle, *Terrapene c. carolina* (Linnaeus): Ecological Monographs, v. 20, no. 4, p. 351–378. [Also available at http://dx.doi.org/10.2307/1943570.]

Stickel, L.F., 1978, Changes in a box turtle population during three decades: Copeia, v. 1978, no. 2, p. 221–225. [Also available at http://dx.doi.org/10.2307/1443554.]

Stickel, L.F., 1996, Obituary—William H. Stickel, 1912–1996: Wildlife Society Bulletin, v. 24, no. 2, p. 369–370. [Also available at http://www.jstor.org/stable/3783137.]

Stickel, W.H., 1942, A partially scaleless garter-snake: Copeia, v. 1942, no. 3, p. 181. [Also available at http://dx.doi.org/10.2307/1438220.]

Uhler, F.M., 1944, Facts about snakes: Washington, D.C., U.S. Fish and Wildlife Service, Wildlife Leaflet No. 257, 10 p. [Also available at https://archive.org/details/factsaboutsnakes103usfi.]

Uhler, F.M., Cottam, Clarence, and Clark, T.E., 1939, Food of snakes of the George Washington National Forest, Virginia: Transactions of the North American Wildlife Conference, v. 4, p. 605–622.

Weir, L.A., and Mossman, M.J., 2005, North American Amphibian Monitoring Program (NAAMP), *in* Lannoo, Michael, ed., Amphibian declines—The conservation status of United States species: Berkeley, CA, University of California Press, p. 307–313.

Whiting, M.J., Dixon, J.R., Greene, B.D., Mueller, J.M., Thornton, O.W., Jr., Hatfield, J.S., Nichols, J.D., and Hines, J.E., 2008, Population dynamics of the Concho water snake in rivers and reservoirs: Copeia, v. 2008, no. 2, p. 438–445. [Also available at http://www.pwrc.usgs.gov/prodabs/hatfield/Whiting_et_al_2008.pdf.]

Wynn, A.H., Reynolds, R.P., Buden, D.W., Falanruw, Marjorie, and Lynch, Brian, 2012, The unexpected discovery of blind snakes (Serpentes: Typhlopidae) in Micronesia—Two new species of *Ramphotyphlops* from the Caroline Islands: Zootaxa, v. 3172, p. 39–54. [Also available at http://www.mapress.com/zootaxa/2012/f/z03172p054f.pdf.]

Chesapeake Bay Contaminant Studies by Patuxent Wildlife Research Center Scientists

By Barnett A. Rattner

Chesapeake Bay is the largest estuary in the United States (165,000 square kilometers [63,700 square miles]). In the 1600s, the bay "teemed with life," and forests covered 95 percent of the watershed (Alliance for the Chesapeake Bay, 1998, unpub. fact sheet). The arrival of European settlers was accompanied by the clearing of forests and gradual conversion of wetlands to agriculture and urban centers, and, in the centuries that followed, the ability of the watershed to keep contaminants from reaching the bay and its tributaries diminished (Baldwin and others, 2012). In addition to the loss of habitat, overharvesting of living resources, as well as agricultural, industrial, and urban activities, have had major effects on invertebrate, fish, and wildlife populations residing in the bay and its watershed.

During its 75-year history, staff of the Patuxent Research Refuge and its successor research entities (Patuxent) and affiliates have contributed greatly to our present-day understanding of Chesapeake Bay. Our contaminant biologists (today more commonly referred to as wildlife toxicologists or ecotoxicologists) have conducted innumerable laboratory and controlled exposure investigations (for example, egg injection studies involving developing embryos in incubators, young and adult wildlife in cages or pens), field monitoring, and hypothesis-driven studies. By using a combined laboratory/pen-field approach, Patuxent scientists have elucidated both the direct and indirect effects of environmental contaminants on wildlife. Notably, some of the first studies of the effects of dichlorodiphenyltrichloroethane (DDT) on wild birds and mammals were conducted in forests at Patuxent or surrounding areas within the bay watershed, and their place in the history of wildlife toxicology is well established (for example, studies by Robert Stewart, Lucille Stickel, Chandler Robbins, Clarence Cottam, and others as described in an historical review by Rattner [2009]). Although the geographic scope of nearly all our studies is broad, this chapter is an historical perspective of Patuxent research efforts that specifically examined contaminant exposure and resulting effects on Chesapeake Bay wildlife and their supporting habitat.

Early Years

Through interviews with retirees who worked at Aberdeen Proving Ground, the U.S. Army facility in Aberdeen, MD, it was learned that an unknown quantity of white phosphorus munitions is said to be buried offshore (that is, a barge containing munitions may have been purposefully or accidentally sunk) in the vicinity of Black Point (upper Chesapeake Bay near U.S. Army Aberdeen Proving Ground) between 1922 and 1925 (John Paul and John Wrobel, U.S. Army Garrison, Aberdeen Proving Ground, MD, oral commun., 2012). In addition, large segments of open water in this region had been used for decades as an ordnance impact area. Undoubtedly, ignited white phosphorus from artillery rounds was extinguished upon entering the bay. In 1933, the so-called burial site was disturbed by a hurricane. Resuspended white phosphorus may have been responsible for the large waterfowl kill that followed (ducks were said to have "turned pink and died") (see the U.S. Environmental Protection Agency Superfund Record of Decision [U.S. Environmental Protection Agency, 1991]). In 1939, Secretary of the Interior Harold Ickes designated parts of the site as a Migratory Waterfowl Closed Area for waterfowl hunting. These events and subsequent waterfowl die-offs may have been the impetus for a study of white phosphorus toxicity in mallards (*Anas platyrhynchos*) and American black ducks (hereafter black ducks) (*Anas rubripes*) (Coburn and others, 1950). In one of the first studies with captive waterfowl at Patuxent, survival of, and hematologic and histopathological responses to, acute and chronic exposure regimens were examined. Remarkably, tissue phosphorus concentrations in control and treated birds were determined and compared by using inferential statistical methods. Don Coburn and coworkers (1950) evaluated phosphorus concentrations in redhead ducks (*Aythya americana*) collected from northern Chesapeake Bay that were suspected to have died from phosphorus poisoning and concluded "it appears probable" the birds had been killed by ingestion of elemental phosphorus. This issue reemerged and was scientifically revisited following frequent waterfowl die-offs at a military firing range on the Eagle River Flats, AK, from 1980 to the mid-1990s (reviewed by Sparling, 2003). The U.S. Army has since banned the firing of white phosphorus rounds over the wetlands at Eagle River Flats (U.S. Department of Defense, 2007).

1960s

Following the publication of "Silent Spring" (Carson, 1962), a National Pesticide Monitoring Program was initiated in response to public concern (Johnson and others, 1967). The Bureau of Sport Fisheries and Wildlife of the U.S. Fish and Wildlife Service (USFWS), including staff at Patuxent, collected starlings (*Sturnus vulgaris*) (initially at 44 locations, then at 110 locations), obtained hunter-collected mallard and black duck wings from nearly every state in the continental United States (organized into the four North American Flyways), and was sent dead golden eagles (*Aquila chrysaetos*) and bald eagles (*Haliaeetus leucocephalus*) from many locations across the country (Johnson and others, 1967). Samples initially were analyzed for organochlorine pesticides. Many Patuxent scientists contributed to the nationwide monitoring of starlings and duck wings in the decades that followed. The suite of analytes was expanded to include polychlorinated biphenyls (PCBs) and metals, and results were chronicled in special USFWS reports and scientific journal publications (Schmitt and Bunck, 1995). Because these monitoring schemes focused on nationwide trends over time, little information can be derived with respect to comparisons of contaminant concentrations between states or within a particular estuary, such as Chesapeake Bay.

Examination of data obtained from 69 moribund or dead bald eagles collected in 25 states from 1966 to 1968 included one specimen from the Chesapeake Bay region. That eagle contained a dieldrin concentration of 4.3 micrograms per gram (µg/g) brain tissue on a wet weight (ww) basis, which may have contributed to its death (Mulhern and others, 1970), and another suspected dieldrin poisoning (11 µg/g ww) was documented in 1970 (Belisle and others, 1972). Regionally focused studies also were conducted during this period. For example, a survey of organochlorine pesticide residues in black duck eggs was conducted in 1964 (Reichel and Addy, 1968). The dataset indicated that eggs from the Chesapeake Bay region contained lower concentrations of dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethylene (DDE), dichlorodiphenyldichloroethane (DDD), and dieldrin than samples from New Jersey, New York, Massachusetts, and other North Atlantic States.

Perhaps one of the most classic avian contaminant field studies of this era entailed the exchange of osprey (*Pandion haliaetus*) eggs from nests on the lower Potomac River, MD, with eggs from Old Lyme, Niantic, Trumbull Airport, and Mason's Island in Connecticut by Stan Wiemeyer, Paul Spitzer, and others (Wiemeyer and others, 1975). The results of this highly cited study indicate that the most probable cause of poor reproduction in Connecticut ospreys was DDE, dieldrin, and PCB contamination, of both fish consumed and eggs laid by ospreys.

Young ospreys in nest on the James River, VA, 2012. Photo by Rebecca S. Lazarus, U.S. Geological Suvey.

1970s

During the 1970s, Patuxent scientists devoted much effort to generating basic toxicological data on pesticides, industrial compounds, and metals through controlled-exposure studies with penned or caged birds (for example, Northern bobwhite [*Colinus virginianus*], Japanese quail [*Coturnix japonica*], mourning doves [*Zenaida macroura*], waterfowl, raptors, and black-crowned night-herons [*Nycticorax nycticorax*]. In addition, many regional or national contaminant-monitoring efforts included Chesapeake wildlife and, in some instances, research studies focused directly on the bay.

A study of ospreys on the Potomac River in 1970 and 1971 revealed low reproductive success, and indicated that the effects of pesticides and other contaminants could be investigated as a possible cause (Wiemeyer, 1971, 1977). Osprey eggs collected from 1970 to 1978 contained about 3 µg/g DDE ww; other organochlorine pesticides were present at much lower concentrations, yet PCBs were present at concentrations as high as 20 µg/g ww (Wiemeyer and others, 1988). In some instances, eggshell thinning approached levels (greater than 15 percent) that are associated with breakage and reduced reproductive success. Using aerial surveys by Patuxent scientists Chuck Henny, Vern Stotts, and others, Henny and others (1974) estimated the Chesapeake Bay osprey population to be about 1,450 nesting pairs in 1973; however, only 7 of these nesting pairs were observed in the northwestern part of the bay, and only 2 nesting pairs were observed on the James River and nearby tributaries. These results triggered several osprey ecotoxicological investigations in the subsequent decades.

During this era, Chesapeake Bay bald eagle eggs that failed to hatch contained greater concentrations of organochlorine pesticides than those from 13 other states (Wiemeyer and others, 1984), and eggshells were significantly thinner (-11 percent in Maryland and -18 percent in Virginia) than museum samples collected before the introduction of DDT (before 1946). In a continuation of this sampling effort, DDE concentrations in eagle eggs had declined by 1980–84, although shell thickness still averaged 13 to 14 percent less than pre-1946 values (Wiemeyer and others, 1993).

At about the same time (1972–73), eggs of barn owls (*Tyto alba*) were collected from offshore duck blinds on the lower Potomac River (Klaas and others, 1978). Eggshell thickness was determined to be inversely related to DDE, DDD, and dieldrin concentrations, and reproduction (1.7 young per clutch) was slightly less than that necessary to maintain population stability. In a long-term study of red-shouldered hawk (*Buteo lineatus*) populations in the Patuxent River Valley (1943–71), Henny and coworkers (Henny and others, 1973) suggested that concentrations of DDT, its metabolites, and dieldrin may have caused as much as a 9-percent decrease in eggshell thickness in samples collected in 1971, although it was unlikely that such exposure was having detrimental effects on hawk populations in this region.

As part of an eastern United States sampling effort in 1972 and 1973, concentrations of DDE and PCBs in eggs collected from great blue herons (*Ardea herodias*) and cattle egrets (*Bubulcus ibis*) nesting in the Potomac River were determined to be low to moderate compared to those in eggs collected from nests in other regions (Ohlendorf and others, 1979). In a highly cited publication, Patuxent scientist Harry

Banded young ospreys on nest in Chesapeake Bay, 2012. Photo by Rebecca S. Lazarus, U.S. Geological Survey.

Ohlendorf and others (1978) described contaminants in black-crowned night herons (*Nycticorax nycticorax*) and determined that eggs in Chincoteague, VA, in the Chesapeake Bay region (but not the bay proper) contained low to moderate concentrations of chlorinated hydrocarbons and metals; no evidence of substantial shell thinning was observed. This colony was used as a reference site for many studies in subsequent decades. In 1978, black duck eggs were collected along the Atlantic Flyway, and concentrations of DDE, PCBs, and mercury were determined to be the lowest in the Chesapeake Bay region (Pennsylvania, Maryland, Virginia) compared to more northerly locations extending into Nova Scotia (Haseltine and others, 1980).

Pesticide residues in carcass and brain, and metals in liver and kidney, were quantified in a subset of 15 ospreys found dead in the Chesapeake Bay region (1964–73; Wiemeyer and others, 1980). Large concentrations of organochlorine pesticides and PCBs were detected in a few individuals (for example, greater than 40 µg/g ww in brain or carcass for DDE and PCBs), although the extreme values for mercury and lead in these Chesapeake Bay region samples were generally lower than values for samples from New York, New Jersey, Ohio, and Florida. Other geographically broad-scale efforts to monitor carcasses and tissues that included samples from the Chesapeake Bay drainage area used American woodcock (*Scolopax minor*) (Clark and McLane, 1974), mourning doves (Kreitzer, 1974), and herons (Ohlendorf and others, 1981). Concentrations of chlorinated hydrocarbons and mercury in these samples were generally moderate compared to concentrations in samples from other regions in the United States. One possible exception was dieldrin, which was implicated in several poisonings of bald eagles in the Chesapeake Bay region in the 1960s and 1970s (Cromartie and others, 1975; Prouty and others, 1977). Furthermore, of 27 herons found dead in the Chesapeake Bay region from 1966 to 1978, 3 great blue herons and 2 cattle egrets contained dieldrin residues that probably contributed to their deaths (Ohlendorf and others, 1981).

To investigate the potential role of contaminants in declining populations of canvasbacks (*Aythya valisineria*), blood samples were collected from birds trapped at two Chesapeake Bay locations (Westmoreland State Park in Virginia and Cove Point in Maryland) by Patuxent scientists Mike Dieter and Matt Perry from 1972 to 1974 (Dieter and others, 1976). Abnormal enzyme activity was detected in about 20 percent of the samples; plasma aspartate aminotransferase activity was positively correlated with PCB and DDE concentrations in blood, and whole blood delta-aminolevulinic acid dehydratase (ALAD) activity was inversely related to lead concentrations in blood. This was the first published report describing the use of ALAD inhibition as a biomarker of lead exposure in wildlife, and its use in lead studies and Natural Resource Damage Assessments continues to the present day (2016). In a related study, canvasback carcass and tissue samples collected in 1973, 1975, and 1976 were analyzed for chlorinated hydrocarbons and several metals (cadmium, chromium, copper, lead, mercury, and zinc); for most individuals, concentrations were less than levels known to cause adverse effects (White and others, 1979).

One of many necropsy case reports described by Patuxent scientist Lou Locke involved a moribund tundra swan (*Cygnus columbianus*) collected on the bank of Seneca Creek in Essex, MD (Locke and Young, 1973); this case report is particularly important because it may have been the first paper attributing lead poisoning in a swan to ingestion of fishing tackle. Patuxent veterinarian Jim Carpenter contributed to another case report that described an immature bald eagle recovered from western Maryland that died during treatment and rehabilitation attempts (Jacobson and others, 1977). Lead concentrations in tissues were elevated (liver, 22.9 µg/g; kidney, 12.3 µg/g), but most remarkable were the radiograph and necropsy of the gizzard, which contained 20 lead pellets.

Pair of canvasbacks used in contaminant study, Chesapeake Bay, 1976. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Oiled canvasback in Chesapeake Bay, 1978. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Tidal salt marsh in Chesapeake Bay, 1978. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

During this period, Patuxent contaminant studies in mammals were limited. Patuxent scientist Don Clark and coworkers (Clark and Krynitsky, 1978; Clark and Lamont, 1976; Clark and Prouty, 1976) documented DDE and PCB concentrations in several species of bats (big brown bat [*Eptesicus fuscus*], little brown bat [*Myotis lucifugus*], eastern pipistrelle [*Pipistrellus subflavus*]) captured in Maryland and West Virginia. The many purposes of these studies included comparing placental transfer and sensitivity of fetuses to these compounds. In a review published decades later (Clark and Shore, 2001), concentrations of chlorinated contaminants in these bats from the Chesapeake Bay region were moderate to low compared to those in bats from other locations in the United States. Notably, whole-body concentrations of lead in big brown and little brown bats exceeded concentrations determined in meadow voles (*Microtus pennsylvanicus*), white-footed mice (*Peromyscus leucopus*), and short-tailed shrews (*Blarina brevicauda*) in the Chesapeake Bay region, but were comparable to levels measured in bats collected at mining sites (Clark, 1979).

Just after the close of the decade, Harry Ohlendorf (1981) summarized organochlorine contaminant data for birds collected in Chesapeake Bay at the Forty-Sixth North American Wildlife and Natural Resources Conference in Washington, D.C., in 1981. Ohlendorf pointed out that although organochlorine compounds were still present in eggs and tissues, the production of the two compounds of greatest concern, DDT and dieldrin, had been banned for use in the United States, and the manufacture and use of other organochlorine pesticides and industrial compounds had declined (for example, production of Kepone in Hopewell, VA; this compound had contaminated much of the James River [Huggett and Bender, 1980], and was suspended, and sales of PCBs had been restricted). In closing, Ohlendorf states "…it appears that the impact of these chemicals in the future should be much less than in the past 35 years. In the Chesapeake Bay attention should be focused on fish-eating birds, primarily bald eagles and ospreys, but it is unlikely that organochlorines will present a serious threat to these species, or others of the Chesapeake Bay region" (Ohlendorf, 1981).

1980s

Unlike the decline in DDE concentrations observed in bald eagle eggs in the Chesapeake Bay area, a similar trend for DDE in osprey eggs collected at the Glenn L. Martin National Wildlife Refuge, Chesapeake Bay, in 1986 was not statistically supported, and the concentrations present were reported to be large enough to cause a 10-percent eggshell thinning (Audet and others, 1992). At that particular location, PCB concentrations appeared to have declined, and other DDT metabolites and dieldrin were not detected. Results of additional studies of osprey carcasses from Chesapeake Bay (1975–82) revealed that concentrations of some organochlorine compounds had declined substantially (Wiemeyer and others, 1987). Interestingly, the mercury concentration of 21 µg/g ww in the liver of one of the dead ospreys might have contributed to the death of this bird, which was killed when it was struck by a motor vehicle (Wiemeyer and others, 1987).

Departing from the long-standing focus of Patuxent biologists on wildlife, Jim Fleming and coworkers (Fleming and others, 1988) led a series of studies of submerged aquatic vegetation (SAV). Water-quality problems and storms in the bay had long been identified as the most likely causes of dramatic declines in the abundance of SAV, and its loss adversely affected other biota throughout the bay. The toxicity of the widely used herbicide atrazine was tested using sago pondweed (*Potamogeton pectinatus*) grown in sterile cultures (anexic conditions) and in buckets (nonaxenic conditions). At concentrations of 1,000 micrograms per liter, atrazine impaired growth of plants in both axenic and nonaxenic conditions. This bioassay system showed considerable promise for effluent screening and testing in Chesapeake Bay.

In 1987 and 1988, Patuxent scientist Keith Miles collected samples of sediment, composites of various invertebrates, and clams (*Macoma* spp.) in Baltimore Harbor, MD, where large numbers of waterfowl had been observed to feed and rest (Miles and Tome, 1997). These samples were analyzed for 20 metals and metalloids, and concentrations of many elements were greater in invertebrates than in sediment. At some locations, concentrations of aluminum, boron, chromium, mercury, lead, and selenium exceeded toxic thresholds, and it was suggested that individual birds using some of the study areas might be adversely affected, although probably not at the population level. In a companion waterfowl study, concentrations of metals and metalloids were measured in livers of dabbling and diving ducks collected from Baltimore Harbor by Patuxent scientist Mike Tome. Lead concentrations exceeded the 2-µg/g ww threshold for subclinical poisoning in some mallards, black ducks, and scaup (*Aythya* spp.), but mercury, cadmium, and selenium levels were generally well below toxicity thresholds (U.S. Geological Survey, 2014; Rattner and McGowan, 2007).

Contamination in Baltimore Harbor, MD, 1973. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Toward the end of the decade, Patuxent scientists Ohlendorf and Fleming (1988) undertook a comparison of Chesapeake Bay and San Francisco Bay waterbird contaminant data collected. Based on field and laboratory studies, the authors concluded that the concentrations of some trace elements and organochlorine compounds in avian tissues and their food items could evoke adverse effects. In Chesapeake Bay, elevated concentrations of cadmium and lead in seaducks, lead in dabbling waterfowl, and DDE in ospreys and bald eagles were of concern, whereas major issues in San Francisco Bay included selenium, cadmium, and mercury in waterfowl and PCBs and DDE in shorebirds and herons. Ohlendorf and Fleming (1988) outlined a research- and information-needs strategy, but ultimately their plan was only partially pursued as a result of funding limitations and shifts in research priorities.

1990s

Patuxent staff members became increasingly involved with the Chesapeake Bay Program, a consortium of Federal, State, and nonprofit agencies and organizations working toward bay restoration. With the passage of the 1987 Chesapeake Bay Agreement, we began to serve on committees and collaborate with other scientists to develop guidelines for the protection of habitat, water quality, and living resources in Chesapeake Bay. At about this time, many of our researchers developed long-lasting collaborations with contaminant biologists (operational staff) at the Chesapeake Bay field office of the USFWS that continue to this day (2016). Gary H. Heinz and Stan Wiemeyer prepared a chapter titled "Effects of Contaminants on Birds" (Heinz and Wiemeyer, 1991) in the frequently cited compendium "Habitat Requirements for Chesapeake Bay Living Resources: A Report from the Chesapeake Bay Living Resources Task Force" (Funderburk and others, 1991). They describe the history of contaminant effects on birds of Chesapeake Bay and point out that the banning of the most harmful organochlorine pesticides and the replacement of lead shot with steel shot has reduced poisoning and reproductive problems. Nevertheless, they suggest that contaminants such as cadmium, petroleum (oil), and industrial chemicals could adversely affect avian species.

A small nesting colony of black-crowned night herons became established in the Baltimore Harbor area in 1979 and had grown to 300 nests by 1990, constituting the largest colony of this species in Maryland. Remarkably, the foraging habits of this colony were concentrated in this highly industrialized area (Erwin and others, 1991), one of three U.S. Environmental Protection Agency-designated Chesapeake Bay Regions of Concern. The colony was popularized in an article by Patuxent scientist Mike Erwin titled "Industrial Strength Herons," which appeared in "Maryland Magazine" (Erwin and others, 1990). In 1991, Mark Melancon began a study examining contaminant exposure and hepatic cytochrome P450 induction (a biochemical biomarker of polyhalogenated hydrocarbon exposure) in pipping embryos and nestlings from the Baltimore Harbor heron colony and at a colony in Rock Creek Park in Washington, D.C. (Rattner and others, 1997). Cytochrome P450-associated monooxygenase enzymes were induced more than fivefold in pipping embryos from Baltimore Harbor and to a smaller degree in those from Rock Creek Park, and concentrations of organochlorine contaminants in pipping embryos and nestlings were markedly elevated compared to those collected from the Chincoteague Bay reference site. The concentration of some PCB congeners (numbers 77 and 126) actually exceeded values observed in this species in the Great Lakes and appear to have been partly responsible for cytochrome P450 induction (Rattner and others, 1997).

These results were the impetus for testing the hypothesis that PCBs might be leading to the declining size of the Baltimore Harbor heron colony. In a follow-up study conducted in 1998, USFWS Chesapeake Bay field office biologist Pete McGowan and I determined that the heron colony had moved about 2 kilometers (1.2 miles) south to Fort Carroll, a mid-19th-century military structure built by Robert E. Lee before the Civil War. In a large-scale study, concentrations of 12 arylhydrocarbon receptor-active PCB congeners and dioxin-related toxic equivalents were more than 35 times greater in sampled eggs from Baltimore Harbor than in those from the reference site in southern Chesapeake Bay (Holland Island). Seventy-four percent of the nests produced at least one chick, and productivity (2.05 young per nest) was adequate to maintain a stable population (Rattner and others, 2001). No significant relation was found between hatching, fledging, or overall reproductive success and concentrations of PCBs and toxic equivalents. The authors concluded that contaminants were not having a dramatic effect on reproduction in the Baltimore Harbor heronry. In the years that followed, the numbers of black-crowned night herons at Fort Carroll continued to decrease to a mere 17 pairs in 2008 (D.F. Brinker, Maryland Department of Natural Resources, oral commun., 2008), and this now-mixed waterbird colony was dominated by double-crested cormorants (*Phalacrocorax auritus*), herring gulls (*Larus argentatus*), and cattle egrets.

Led by colleagues of the USFWS Chesapeake Bay field office, Mark Melancon and Dave Hoffman of Patuxent assisted with a study of potential contaminant effects in great blue herons nesting at Mason Neck National Wildlife Refuge on the banks of the Potomac River in Lorton, VA, in 1997 (Johnson and others, 2001). Eggs were collected and artificially incubated, and biochemical (cytochrome P450 and measures of oxidative stress) and eggshell-thickness measurements did not differ from those for the Coaches Island reference site. Results indicated that great blue herons at Mason Neck, the largest great blue heron colony in Virginia, were probably not being adversely affected by polyhalogenated contaminants.

As part of a study examining potential endocrine disruptive effects of PCBs, Patuxent scientist John French reported that common tern (*Sterna hirundo*) eggs from South Sand Point (off Barren Island in Maryland and Virginia) in 1994 contained relatively low levels of Aroclor 1260 (0.44–1.50 µg/g ww) (U.S. Geological Survey, 2014; Rattner and McGowan, 2007). As part of this effort, eggs also were collected from Bodkin Island, MD, in 1997 and contained less than 10 micrograms total PCB per gram lipid; Bodkin Island served as a comparative reference site for the more contaminated samples from Ram Island in Buzzards Bay, MA (French and others, 2001). There was no evidence that the concentrations of steroid hormones that were maternally deposited in eggs were affected by contaminant exposure.

Tree swallow (*Tachycineta bicolor*) eggs and nestlings were collected from the Patuxent River, a tributary to the middle Chesapeake Bay, to serve as a reference for PCB-contaminated sites in Indiana, New York, and Pennsylvania (Yorks, 1999). As expected, total PCB concentrations in samples from the Patuxent reference site (eggs, 0.69 µg/g ww; nestling carcass, 0.29 µg/g ww) were much lower than those in samples from the PCB-contaminated sites (eggs, 0.94–4.6 µg/g ww; nestling carcass, 0.17–18.5 µg/g ww).

Following an avian cholera outbreak in 1994, 41 long-tailed duck (*Clangula hyemalis*) carcasses were collected throughout Chesapeake Bay (Mashima and others, 1998). Liver and kidney cadmium concentrations were greater in birds that succumbed to cholera than in apparently healthy birds collected during 1985–87. The authors suggested that cadmium may have contributed to cholera susceptibility in these ducks, and concentrations of lead, mercury, and selenium in tissues were probably too low to evoke immunotoxicity. The authors also indicated that weight loss owing to cholera could have concentrated metals in tissues.

As part of a series of studies examining tissue uptake of metals from ingested soil and sediment, Nelson Beyer, Dan Day, and other Patuxent colleagues collected mute swans (*Cygnus olor*) from several locations in Chesapeake Bay (for example, Bloodsworth Island, Horseheads Wetland Center, and Eastern Neck and Blackwater National Wildlife Refuges) (Beyer and others, 1998). Concentrations of metals in sediment were low, and concentrations in liver were considered to be at background levels for this species. Copper concentrations were remarkably high (as much as 1,200 milligrams per kilogram dry weight [dw]); apparently swans, in the absence of environmental contamination, can accumulate large quantities of copper in the liver, far more than other species of waterfowl. Although this study revealed little about the hazards posed by sediment to mute swans throughout the bay, it demonstrated the importance of sediment ingestion for the accumulation of lead in mute swans. Additional studies near Aberdeen Proving Ground indicated that hepatic lead, cadmium, copper, and selenium concentrations did not represent a toxic threat to the swans (Beyer and Day, 2004).

Some heavy metals can be incorporated into feathers at the time they are grown, and the sampling of feathers has gained some acceptance as a minimally invasive sublethal contaminant monitoring technique. My graduate student assistant, Nancy Golden, collected feathers from black-crowned night heron nestlings and determined lead concentrations in herons from Baltimore Harbor to average 0.32 µg/g dw, which was greater than those in feathers collected from Chincoteague

Osprey on nest in Baltimore Harbor, MD, 2011. Photo by Rebecca S. Lazarus, U.S. Geological Survey.

Bay and Holland Island (less than or equal to 0.13 µg/g dw) (Golden and others, 2003b). In a related study of lead-dosed heron nestlings, red blood cell ALAD activity was inversely related to lead concentrations in feathers (Golden and others, 2003a); thus, lead concentrations in feathers of some heron nestlings from Baltimore Harbor might be great enough to cause enzyme inhibition and impaired heme (porphyrin ring component of hemoglobin) synthesis.

Patuxent staff member Mark Melancon collaborated for several years with a team of scientists investigating contaminant exposure, pathological lesions, and cytochrome P450 induction in brown bullheads (*Ameiurus nebulosus*) collected from highly contaminated locations in the Chesapeake Bay area, including the Anacostia River near Washington, D.C., and Back River and Furnace Creek near Baltimore (Pinkney and others, 2001, 2004). These studies documented tumor prevalence; concentrations of DDT, PCBs, and various polynuclear aromatic hydrocarbons (PAHs); and cytochrome P450 induction. In some instances, tumor prevalence was associated with biliary PAH concentrations. Some of the skin tumors were rather grotesque and received considerable attention in the media.

2000s

With recovery and expansion of the Chesapeake osprey population in the 1990s, birds began nesting in some of the most contaminated sites in the bay, including Baltimore Harbor, and the Anacostia and Elizabeth Rivers. In 2000 and 2001, a large-scale study was conducted in which osprey eggs were collected from nests in these Chesapeake Bay Regions of Concern and nearby tributaries (Rattner and others, 2004). Concentrations of DDE, dieldrin, and chlordane in eggs collected from the middle Potomac River in 2000 were less than half those observed in 1970s, and there were no effects on reproductive success when compared to the reference sites (South, West, and Rhode Rivers). However, shell thickness of eggs from the Anacostia River and middle Potomac River averaged 8.7 percent less than in the pre-DDT era, and more than half of these sampled eggs contained DDE at concentrations within the 95-percent confidence interval (1.2–3.0 µg/g ww) associated with 10-percent eggshell thinning. Compared to total PCB values reported in eggs collected in the 1970s and 1980s (Wiemeyer and others, 1988), concentrations in osprey eggs in the 2000 and 2001 samples had not declined. Notably, total PCBs in the reference area averaged more than 4 µg/g ww, which alerted fisheries biologists to a potential hazard, eventually leading to a human-health fish consumption advisory for some species in the South River (Joseph Beaman, Maryland Department of the Environment, oral commun., 2002). Concentrations of toxicologically potent coplanar and semicoplanar PCB congeners were similar among study sites, and dioxin-like toxic equivalents were not unlike values reported for the Delaware Bay and the Great Lakes.

Several groups of emerging contaminants also were quantified in these osprey egg samples. Perhaps the most interesting group was the polybrominated diphenyl ethers

(PBDEs), which are flame retardants; concentrations approached 1 µg/g ww, which were some of the greatest values reported in bird eggs at that time. Follow-up PBDE egg injection studies indicated that pipping and hatching success might be adversely affected at 1.8 µg/g ww (McKernan and others, 2009). Perfluorinated surfactants also were detected in osprey eggs, although concentrations were well below adverse-effect levels. Alkylphenol and ethoxylate surfactants occasionally were detected in low nanogram-per-gram wet weight quantities, although effects of this putative endocrine disruptor in birds have yet (2016) to be definitively verified. Blood and feather samples also were collected from 40- to 45-day old osprey nestlings, and results of analyses indicated that concentrations of several heavy metals (cadmium, lead, mercury) were well below toxicity thresholds (Rattner and others, 2008).

A reevaluation of contaminant exposure, biomarker responses, and potential reproductive effects in ospreys nesting in several tributaries and in Regions of Concern was initiated in 2011. In this large-scale collaborative study, research trainee Rebecca Lazarus and I are examining food-web transfer of legacy-halogenated contaminants, pharmaceuticals, and personal care products in water, fish, and ospreys (Lazarus and others, 2010). Results for legacy contaminants in osprey eggs revealed that concentrations of DDE are below thresholds associated with eggshell thinning and total PBDE concentrations have declined by 40 percent in the past decade, although concentrations of total PCBs in eggs from Baltimore Harbor and the Elizabeth River have remained unchanged (Lazarus and others, 2015). Of 23 pharmaceuticals measured in samples from the bay, 18 analytes were detected in water and 8 were detected in plasma from fish; only 1 of the 23 compounds (the antihypertensive diltiazem) was detected in nestling osprey plasma, but at concentrations well below the human therapeutic plasma concentration (Lazarus and others, 2014). Although there was some evidence of genetic damage in osprey nestlings from the most industrialized regions of the bay, overall findings document the continued recovery of the Chesapeake Bay osprey population (Lazarus and others, 2015).

Over the years, there have been many oil spills in Chesapeake Bay (about 500 incidents annually); fortunately, most have been small events. In 2000, a pipeline rupture released about 126,000 gallons of no. 2 and no. 6 fuel oil at the Potomac Electric Power Company Chalk Point Facility near Aquasco, MD. The spill spread to Swanson Creek, a tributary to the Patuxent River, and killed about 55 birds (principally waterfowl, ospreys, herons, gulls, and terns), and 109 oiled birds were collected for rehabilitation (Cardano, 2001; McGee and others, 2001). This event occurred in April and was coincident with nesting of many species. Patuxent biometrician Jeff Hatfield provided statistical assistance to Daniel Murphy and Craig Koppie of the USFWS Chesapeake Bay field office in evaluating reproductive success of great blue herons and osprey. Fortunately, nest success of herons and ospreys did not seem to be adversely affected by the spill (Cardano, 2001; McGee and others, 2001).

Barnett Rattner, U.S. Geological Survey (left), and Pete McGowan, U.S. Fish and Wildlife Service, approaching an osprey nest by boat in Chesapeake Bay, 2013. Photo by Reese F. Lukei, Jr., Center for Conservation Biology, College of William and Mary, Williamsburg, VA.

In 2001, reports of dead and dying waterbirds at the Poplar Island Complex, Kent Island, and Grasonville, MD, coincided with several harmful algal blooms (HABs). Most prominent was the mortality event at the Poplar Island Complex involving about 100 great blue herons. Results of necropsies performed by Patuxent veterinarian Glenn Olsen were consistent with steatitis (inflammation of adipose tissue), and microcystin toxins from cyanobacteria (*Anabaena* spp.) were detected in water samples and in tissues of dead herons. These HABs and the bird die-offs recurred in 2004 and 2005, and several hypotheses were developed (but remain untested) to examine the role of HABs and diet in steatitis and death of herons (Rattner and others, 2006).

As part of an interspecific study examining the comparative sensitivity of birds to PBDE, common tern eggs were collected from Poplar Island, MD, in 2010 (Rattner and others, 2013). Six eggs were chemically analyzed, and all were determined to contain low levels of organochlorine pesticides (less than 0.08 µg/g ww), total PCBs (less than 0.45 µg/g ww), and total PBDEs (less than 0.05 µg/g ww), indicating that eggs from this mid-Chesapeake Bay location could be used to study the commercial PBDE DE-71 formulation for embryotoxicity.

In their continued study of bullheads from many Chesapeake Bay tributaries, investigators examined tumor prevalence and biomarkers of genotoxicity (Pinkney and others, 2011). Natalie Karouna-Renier identified DNA adducts in liver tissue of bullheads collected from the South and Anacostia Rivers, although this endpoint did not seem to be associated with liver- or skin-tumor prevalence.

Rattner and McGowan (2007) reviewed the potential hazards of contemporary environmental contaminants to avifauna in the Chesapeake Bay estuary by using the Contaminants Exposure and Effects—Terrestrial Vertebrates database (U.S. Geological Survey, 2014). They identified several groups of contaminants (for example, dioxins, dibenzofurans, rodenticides, pharmaceuticals, personal care products) that have not been systematically examined and highlighted the need for toxicological evaluation of birds found dead, and perhaps an avian ecotoxicological monitoring program.

Conclusions

Patuxent scientists have studied environmental contaminants and contamination processes in Chesapeake Bay for decades. Our efforts have been intermittent, reflecting ever-changing research priorities, perceived needs of natural-resource managers, and fluctuating budgets. During the organochlorine pesticide era, Chesapeake Bay served as a convenient outdoor laboratory to monitor exposure and test hypotheses. In fact, this estuary provided remarkable evidence of “a great natural experiment,” a wonderful phrase first coined by Patuxent contaminant biologist Bill Stickel and passed on to me by my colleague Gary H. Heinz. After the use of certain organochlorine pesticides was restricted, residues in tissues of wildlife and in their foods declined, toxic effects were abated, and, in some instances, wildlife populations (for example, osprey, bald eagle, peregrine falcon [*Falco peregrinus*]) recovered. With each successive decade, new chemicals and stressor interactions emerge that we must consider and evaluate. In the last several decades, Chesapeake Bay has been a source of plants and animals that can be used to study contaminant uptake, metabolism, clearance, and toxicity in our laboratories and animal holding facilities. We have contributed to the recovery of parts of the Chesapeake Bay ecosystem, but have come to the realization that it will never return to the condition that existed before the arrival of European settlers to the New World.

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References Cited

Audet, D.J., Scott, D.S., and Wiemeyer, S.N., 1992, Organochlorines and mercury in osprey eggs from the eastern United States: Journal of Raptor Research, v. 26, no. 4, p. 219–224. [Also available at https://sora.unm.edu/node/53311.]

Baldwin, A.H., Kangas, P.J., Megonigal, J.P., Perry, M.C., and Whigham, D.F., 2012, Coastal wetlands of Chesapeake Bay, *in* Batzer, D.P., and Baldwin, A.H., eds., Wetland habitats of North America—Ecology and conservation concerns: Berkeley, California, University of California Press, p. 29–43. [Also available at https://repository.si.edu/bitstream/handle/10088/19190/serc_Baldwin_et_al_2012.pdf.]

Belisle, A.A., Reichel, W.L., Locke, L.N., Lamont, T.G., Mulhern, B.M., Prouty, R.M., DeWolf, R.B., and Cromartie, Eugene, 1972, Residues of organochlorine pesticides, polychlorinated biphenyls and mercury and autopsy data for bald eagles, 1969 and 1970: Pesticides Monitoring Journal, v. 6, no. 3, p. 133–138. [Also available at http://biodiversitylibrary.org/page/26095031.]

Beyer, W.N., and Day, Daniel, 2004, Role of manganese oxides in the exposure of mute swans (*Cygnus olor*) to Pb and other elements in the Chesapeake Bay, USA: Environmental Pollution, v. 129, no. 2, p. 229–235. [Also available at http://dx.doi.org/10.1016/j.envpol.2003.10.026.]

Beyer, W.N., Day, Daniel, Morton, Anna, and Pachepsky, Yakov, 1998, Relation of lead exposure to sediment ingestion in mute swans on the Chesapeake Bay, USA: Environmental Toxicology and Chemistry, v. 17, no. 11, p. 2298–2301. [Also available at http://dx.doi.org/10.1002/etc.5620171121.]

Cardano, Steve, 2001, Reproductive success of osprey (*Pandion haliaetus*) nesting in the vicinity of the Chalk Point oil spill—Final report, November, 2001: National Oceanic and Atmospheric Administration, Damage Assessment, Remediation, and Restoration Program, Chalk Point Natural Resource Damage Assessment Council. [Also available at https://casedocuments.darrp.noaa.gov/northeast/chalk_point/pdf/cpar2034.pdf.]

Carson, R.L., 1962, Silent spring: Boston, MA, Houghton Mifflin, 368 p.

Clark, D.R., Jr., 1979, Lead concentrations—Bats vs. terrestrial small mammals collected near a major highway: Environmental Science and Technology, v. 13, no. 3, p. 338–341. [Also available at http://dx.doi.org/10.1021/es60151a004.]

Clark, D.R., Jr., and Krynitsky, A.K., 1978, Organochlorine residues and reproduction in the little brown bat, Laurel, Maryland—June 1976: Pesticides Monitoring Journal, v. 12, no. 3, p. 113–116. [Also available at http://biodiversitylibrary.org/page/26096667.]

Clark, D.R., Jr., and Lamont, T.G., 1976, Organochlorine residues and reproduction in the big brown bat: Journal of Wildlife Management, v. 40, no. 2, p. 249–254. [Also available at http://dx.doi.org/10.2307/3800422.]

Clark, D.R., Jr., and McLane, M.A.R., 1974, Chlorinated hydrocarbon and mercury residues in woodcock in the United States, 1970–71: Pesticides Monitoring Journal, v. 8, no. 1, p. 15–22. [Also available at http://biodiversitylibrary.org/page/26095565.]

Clark, D.R., Jr., and Prouty, R.M., 1976, Organochlorine residues in three bat species from four localities in Maryland and West Virginia, 1973: Pesticides Monitoring Journal, v. 10, no. 2, p. 44–53. [Also available at http://biodiversitylibrary.org/page/26096130.]

Clark, D.R., Jr., and Shore, R.F., 2001, Chiroptera, *in* Shore, R.F., and Rattner, B.A., eds., Ecotoxicology of wild mammals: New York, John Wiley and Sons, Ltd., p. 159–214.

Coburn, D.R., DeWitt, J.B., Derby, J.V., Jr., and Ediger, Ernest, 1950, Phosphorus poisoning in waterfowl: Journal of the American Pharmaceutical Association, Scientific Edition, v. 39, no. 3, p. 151–158. [Also available at http://dx.doi.org/10.1002/jps.3030390308.]

Cromartie, Eugene, Reichel, W.L., Locke, L.N., Belisle, A.A., Kaiser, T.E., Lamont, T.G., Mulhern, B.M., Prouty, R.M., and Swineford, D.M., 1975, Residues of organochlorine pesticides and polychlorinated biphenyls and autopsy data for bald eagles, 1971–72: Pesticides Monitoring Journal, v. 9, no. 1, p. 11–14. [Also available at http://biodiversitylibrary.org/page/26095865.]

Dieter, M.P., Perry, M.C., and Mulhern, B.M., 1976, Lead and PCB's in canvasback ducks—Relationship between enzyme levels and residues in blood: Archives of Environmental Contamination and Toxicology, v. 5, no. 1, p. 1–13. [Also available at http://dx.doi.org/10.1007/BF02220886.]

Erwin, R.M., Anders, V.P., and Miles-Iverson, K., 1990, Industrial strength herons—The black-crowns of Baltimore: Maryland Magazine, v. 22, no. 3, p. 80.

Erwin, R.M., Hatfield, J.S., and Link, W.A., 1991, Social foraging and feeding environment of the black-crowned night heron in an industrialized estuary: Bird Behaviour, v. 9, no. 1–2, p. 94–102. [Also available at http://dx.doi.org/10.3727/015613890791749037.]

Fleming, W.J., Momot, J.J., and Ailstock, M.S., 1988, Bioassay of phytotoxicity of toxicants to sago pondweed, *in* Lynch, M.T., and Krome, E.C., eds., Understanding the estuary—Advances in Chesapeake Bay research: Solomons, MD, Chesapeake Research Consortium, Publication 129, p. 431–440.

French, J.B., Jr., Nisbet, I.C.T., and Schwabl, Hubert, 2001, Maternal steroids and contaminants in common tern eggs—A mechanism of endocrine disruption?: Comparative Biochemistry and Physiology, part C, v. 128, no. 1, p. 91–98. [Also available at http://dx.doi.org/10.1016/S1532-0456(00)00181-2.]

Funderburk, S.L., Mihursky, J.A., Jordan, S.J., and Riley, David, eds., 1991, Habitat requirements for Chesapeake Bay living resources (2d ed.): Annapolis, MD, prepared for the Chesapeake Bay Program, Living Resources Subcommittee, by the Living Resources Subcommittee, Habitat Objectives Workgroup; and the Chesapeake Research Consortium, Inc., 23 chap. plus app.

Golden, N.H., Rattner, B.A., Cohen, J.B., Hoffman, D.J., Russek-Cohen, Estelle, and Ottinger, M.A., 2003a, Lead accumulation in feathers of nestling black-crowned night herons (*Nycticorax nycticorax*) experimentally treated in the field: Environmental Toxicology and Chemistry, v. 22, no. 7, p.1517–1524. [Also available at http://dx.doi.org/10.1002/etc.5620220713.]

Golden, N.H., Rattner, B.A., McGowan, P.C., Parsons, K.C., and Ottinger, M.A., 2003b, Concentrations of metals in feathers and blood of nestling black-crowned night-herons (*Nycticorax nycticorax*) in Chesapeake and Delaware Bays: Bulletin of Environmental Contamination and Toxicology, v. 70, no. 2, p. 385–393. [Also available at http://dx.doi.org/10.1007/s00128-002-0203-6.]

Haseltine, S.D., Mulhern, B.M., and Stafford, Charles, 1980, Organochlorine and heavy metal residues in black duck eggs from the Atlantic Flyway, 1978: Pesticides Monitoring Journal, v. 14, no. 2, p. 53–57. [Also available at http://biodiversitylibrary.org/page/26096883.]

Heinz, G.H., and Wiemeyer, S.N., 1991, Effects of contaminants on birds, *in* Funderburk, S.L., Mihursky, J.A., Jordan, S.J., and Riley, David, eds., Habitat requirements for Chesapeake Bay living resources (2d ed.): Annapolis, MD, Chesapeake Bay Program, Living Resources Subcommittee, by the Living Resources Subcommittee, Habitat Objectives Workgroup; and the Chesapeake Research Consortium, Inc., p. 23-1–23-9.

Henny, C.J., Schmid, F.C., Martin, E.M., and Hood, L.L., 1973, Territorial behavior, pesticides, and the population ecology of red-shouldered hawks in central Maryland, 1943–1971: Ecology, v. 54, no. 3, p. 545–554. [Also available at http://dx.doi.org/10.2307/1935339.]

Henny, C.J., Smith, M.M., and Stotts, V.D., 1974, The 1973 distribution and abundance of breeding ospreys in the Chesapeake Bay: Chesapeake Science, v. 15, no. 3, p. 125–133. [Also available at http://www.jstor.org/stable/1351027.]

Huggett, R.J., and Bender, M.E., 1980, Kepone in the James River: Environmental Science and Technology, v. 14, no. 8, p. 918–923. [Also available at http://dx.doi.org/10.1021/es60168a001.]

Jacobson, Elliott, Carpenter, J.W., and Novilla, Meliton, 1977, Suspected lead toxicosis in a bald eagle: Journal of the American Veterinary Medical Association, v. 171, no. 9, p. 952–954. [Also available at https://www.researchgate.net/publication/22229831_Suspected_lead_toxicosis_in_a_bald_eagle.]

Johnson, R.E., Carver, T.C., and Dustman, E.H., 1967, Residues in fish, wildlife, and estuaries—Indicator species near top of food chain chosen for assessment of pesticide base levels in fish and wildlife—Clams, oysters, and sediment in estuarine environment: Pesticides Monitoring Journal, v. 1, no. 1, p. 7, 10–13. [Also available at http://biodiversitylibrary.org/page/26093628.]

Johnson, K.N., Pinkney, A.E., Melancon, M.J., and Hoffman, D.J., 2001, Investigation of eggshell thickness and biochemical indicators of contaminant exposure in great blue herons (*Ardea herodias*) from Mason Neck National Wildlife Refuge: Annapolis, MD, U.S. Fish and Wildlife Service, Chesapeake Bay Field Office, CBFO–C01–02, 14 p. [Also available at http://ecos.fws.gov/ServCatFiles/reference/holding/21740.]

Klaas, E.E., Wiemeyer, S.N., Ohlendorf, H.M., and Swineford, D.M., 1978, Organochlorine residues, eggshell thickness, and nest success in barn owls from the Chesapeake Bay: Estuaries, v. 1, no. 1, p. 46–53. [Also available at http://www.jstor.org/stable/1351649.]

Kreitzer, J.F., 1974, Residues of organochlorine pesticides, mercury, and PCB's in mourning doves from the eastern United States—1970–71: Pesticides Monitoring Journal, v. 7, no. 3/4, p. 195–199. [Also available at http://biodiversitylibrary.org/page/26095505.]

Lazarus, R.S., Rattner, B.A., Brooks, B.W., Du, Bowen, McGowan, P.C., Blazer, V.S., and Ottinger, M.A., 2014, Exposure and food web transfer of pharmaceuticals in ospreys (*Pandion haliaetus*)—Predictive model and empirical data: Integrated Environmental Assessment and Management, v. 11, no. 1, p. 118–129. [Also available at http://dx.doi.org/10.1002/ieam.1570.]

Lazarus, R.S., Rattner, B.A., McGowan, P.C., Hale, R.C., Schultz, S.L., Karouna-Renier, N.K., and Ottinger, M.A., 2015, Decadal re-evaluation of contaminant exposure and productivity of ospreys (*Pandion haliaetus*) nesting in Chesapeake Bay regions of concern: Environmental Pollution, v. 205, p. 278–290. [Also available at http://dx.doi.org/10.1016/j.envpol.2015.05.026.]

Lazarus, R.S., Rattner, B.A., and Ottinger, M.A., 2010, Contaminant exposure, food chain transfer and potential health effects on fish and osprey (*Pandion haliaetus*) in Chesapeake Bay: Cumberland, MD, U.S. Geological Survey, Chesapeake Bay Science Workshop, November 17–18, 2010 (abstract).

Locke, L.N., and Young, L.T., 1973, An unusual case of lead poisoning in a whistling swan: Maryland Birdlife, v. 29, no. 3, p. 106–107. [Also available at https://sora.unm.edu/node/132815.]

Mashima, T.Y., Fleming, W.J., and Stoskopf, M.K., 1998, Metal concentrations in oldsquaw (*Clangula hyemalis*) during an outbreak of avian cholera, Chesapeake Bay, 1994: Ecotoxicology, v. 7, no. 2, p. 107–111. [Also available at http://dx.doi.org/10.1023/A:1008820004249.]

McGee, Beth, McGowan, Peter, Hoffman, Mark, Michel, Jacqueline, and Greer, Richard, 2001. Reproductive success of great blue herons (*Ardia [Ardea] herodias*) nesting in Swanson Creek, Maryland during the Chalk Point oil spill—Final report, May 16, 2001: National Oceanic and Atmospheric Administration, Damage Assessment, Remediation, and Restoration Program, Chalk Point Natural Resource Damage Assessment Council, 14 p. [Also available at https://casedocuments.darrp.noaa.gov/northeast/chalk_point/pdf/cpar1987.pdf.]

McKernan, M.A., Rattner, B.A., Hale, R.C., and Ottinger, M.A., 2009, Toxicity of polybrominated diphenyl ethers (de–71) in chicken (*Gallus gallus*), mallard (*Anas platyrhynchos*), and American kestrel (*Falco sparverius*) embryos and hatchlings: Environmental Toxicology and Chemistry, v. 28, no. 5, p. 1007–1017. [Also available at http://dx.doi.org/10.1897/08-318.1.]

Miles, A.K., and Tome, M.W., 1997, Spatial and temporal heterogeneity in metallic elements in industrialized aquatic bird habitats: Environmental Pollution, v. 95, no. 1, p. 75–84. [Also available at http://dx.doi.org/10.1016/S0269-7491(96)00096-6.]

Mulhern, B.M., Reichel, W.L., Locke, L.N., Lamont, T.G., Belisle, Andre, Cromartie, Eugene, Bagley, G.E., and Prouty, R.M., 1970, Organochlorine residues and autopsy data from bald eagles 1966–68: Pesticides Monitoring Journal, v. 4, p. 141–144. [Also available at http://biodiversitylibrary.org/page/26094387.]

Ohlendorf, H.M., 1981, The Chesapeake Bay's birds and organochlorine pollutants: Transactions of the North American Wildlife and Natural Resources Conference, v. 46, p. 259–270.

Ohlendorf, H.M., and Fleming, W.J., 1988, Birds and environmental contaminants in San Francisco and Chesapeake Bays: Marine Pollution Bulletin, v. 19, no. 9, p. 487–495. [Also available at http://dx.doi.org/10.1016/0025-326X(88)90405-5.]

Ohlendorf, H.M., Klaas, E.E., and Kaiser, T.E., 1978, Environmental pollutants and eggshell thinning in the black-crowned night heron, *in* Sprunt, A., IV, Ogden, J.C., and Winckler, S., eds., Wading birds: New York, Dartmouth Printing Company, National Audubon Society research report no. 7, p. 63–82.

Ohlendorf, H.M., Klaas, E.E., and Kaiser, T.E., 1979, Environmental pollutants and eggshell thickness—Anhingas and wading birds in the Eastern United States: U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 216, 94 p.

Ohlendorf, H.M., Swineford, D.M., and Locke, L.N., 1981, Organochlorine residues and mortality of herons: Pesticides Monitoring Journal, v. 14, no. 4, p. 125–135. [Also available at http://www.biodiversitylibrary.org/page/26096965.]

Pinkney, A.E., Harshbarger, J.C., Karouna-Renier, N.K., Jenko, Kathryn, Balk, Lennart, Skarphéðinsdóttir, Halldóra, Liewenborg, Birgitta, and Rutter, M.A., 2011, Tumor prevalence and biomarkers of exposure in brown bullhead (*Ameiurus nebulosus*) in Chesapeake Bay tributaries: Science of the Total Environment, v. 410–411, no. 1, p. 248–257. [Also available at http://dx.doi.org/10.1016/j.scitotenv.2011.09.035.]

Pinkney, A.E., Harshbarger, J.C., May, E.B., and Melancon, M.J., 2001, Tumor prevalence and biomarkers of exposure in brown bullheads (*Ameiurus nebulosus*) from the tidal Potomac River, USA, watershed: Environmental Toxicology and Chemistry, v. 20, no. 6, p. 1196–1205. [Also available at http://dx.doi.org/10.1002/etc.5620200608.]

Pinkney, A.E., Harshbarger, J.C., May, E.B., and Melancon, M.J., 2004, Tumor prevalence and biomarkers of exposure in brown bullhead (*Ameiurus nebulosus*) from Back River, Furnace Creek, and Tuckahoe River, Maryland: Archives of Environmental Contamination and Toxicology, v. 46, no. 4, p. 492–501. [Also available at http://dx.doi.org/10.1007/s00244-003-2252-1.]

Prouty, R.M., Reichel, W.L., Locke, L.N., Belisle, A.A., Cromartie, E., Kaiser, T.E., Lamont, T.G., Mulhern, B.M., and Swineford, D.M., 1977, Residues of organochlorine pesticides and polychlorinated biphenyls and autopsy data for bald eagles, 1973–74: Pesticides Monitoring Journal, v. 11, no. 3, p. 134–137. [Also available at http://biodiversitylibrary.org/page/26096444.]

Rattner, B.A., 2009, History of wildlife toxicology: Ecotoxicology, v. 18, no. 7, p. 773–783. [Also available at http://dx.doi.org/10.1007/s10646-009-0354-x.]

Rattner, B.A., Golden, N.H., Toschik, P.C., McGowan, P.C., and Custer, T.W., 2008, Concentrations of metals in blood and feathers of nestling ospreys (*Pandion haliaetus*) in Chesapeake and Delaware Bays: Archives of Environmental Contamination and Toxicology, v. 54, no. 1, p. 114–122. [Also available at http://dx.doi.org/10.1007/s00244-007-9004-6.]

Rattner, B.A., Lazarus, R.S., Heinz, G.H., Karouna-Renier, N.K., Schultz, S.L., and Hale, R.C., 2013, Comparative embryotoxicity of a pentabrominated diphenyl ether mixture to common terns (*Sterna hirundo*) and American kestrels (*Falco sparverius*): Chemosphere, v. 93, no. 2, p. 441–447. [Also available at http://dx.doi.org/10.1016/j.chemosphere.2013.05.030.]

Rattner, B.A., and McGowan, P.C., 2007, Potential hazards of environmental contaminants to avifauna residing in the Chesapeake Bay estuary: Waterbirds, v. 30, Special Publication 1, p. 63–81. [Also available at http://www.jstor.org/stable/25148277.]

Rattner, B.A., McGowan, P.C., Golden, N.H., Hatfield, J.S., Toschik, P.C., Lukei, R.F., Jr., Hale, R.C., Schmitz-Afonso, Isabelle, and Rice, C.P., 2004, Contaminant exposure and reproductive success of ospreys (*Pandion haliaetus*) nesting in Chesapeake Bay regions of concern: Archives of Environmental Contamination and Toxicology, v. 47, no. 1, p. 126–140. [Also available at http://dx.doi.org/10.1007/s00244-003-3160-0.]

Rattner, B.A., McGowan, P.C., Hatfield, J.S., Hong, C.S., and Chu, S.G., 2001, Organochlorine contaminant exposure and reproductive success of black-crowned night-herons (*Nycticorax nycticorax*) nesting in Baltimore Harbor, Maryland: Archives of Environmental Contamination and Toxicology, v. 41, no. 1, p. 73–82. [Also available at http://dx.doi.org/10.1007/s002440010222.]

Rattner, B.A., Melancon, M.J., Rice, C.P., Riley, Walter, Jr., Eisemann, John, and Hines, R.K., 1997, Cytochrome P450 and organochlorine contaminants in black-crowned night-herons from the Chesapeake Bay Region, USA: Environmental Toxicology and Chemistry, v. 16, no. 11, p. 2315–2322. [Also available at http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1562&context=icwdm_usdanwrc.]

Rattner, B.A., Olsen, G.H., McGowan, P.C., Ackerson, B.K., and McKernan, M.A., 2006, Harmful algal blooms and bird die-offs in Chesapeake Bay—A potential link?: Cambridge, MD, Chesapeake Marshlands National Wildlife Refuge Complex 3rd Annual Science Meeting, March 8, 2006, PowerPoint® presentation, accessed December 21, 2015, at http://www.pwrc.usgs.gov/health/rattner/rattner_blackwaternwr.cfm.

Reichel, W.L., and Addy, C.E., 1968, A survey of chlorinated pesticide residues in black duck eggs: Bulletin of Environmental Contamination and Toxicology, v. 3, no. 3, p. 174–179. [Also available at http://dx.doi.org/10.1007/BF01684453.]

Schmitt, C.J., and Bunck, C.M., 1995, Persistent environmental contaminants in fish and wildlife, *in* LaRoe, E.T., Farris, G.S., Puckett, C.E., Doran, P.D., and Mac, M.J., Our living resources—A report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems: Washington, D.C., U.S. Department of the Interior, National Biological Service, p. 413–416. [Also available at https://archive.org/details/ourlivingresourc00unit.]

Sparling, D.W., 2003, White phosphorus at Eagle River Flats, Alaska—A case history of waterfowl mortality, *in* Hoffman, D.J., Rattner, B.A., Burton, G.A., and Cairns, John, Jr., eds., Handbook of ecotoxicology (2d ed.): Boca Raton, FL, Lewis Publishing, Inc., p. 767–785.

U.S. Department of Defense, 2007, Preparation of an Environmental Impact Statement (EIS) for resumption of year-round live-fire training at Eagle River Flats (ERF), Fort Richardson, AK: Federal Register, v. 72, p. 46447–46448, accessed December 30, 2015, at https://federalregister.gov/a/07-4038.

U.S. Environmental Protection Agency, 1991, Superfund Record of Decision, USA Aberdeen, Michaelsville, Maryland—First remedial action—Final: Washington, D.C., U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, EPA/ROD/R03-91/126, 17 p., accessed December 29, 2015, at http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=91003DNR.TXT.

U.S. Geological Survey, 2014, Contaminant exposure and effects—Terrestrial vertebrates database, version 11.0, July 2014: accessed December 29, 2015, at http://www.pwrc.usgs.gov/contaminants-online/pages/CEETV/CEETVintro.htm.

White, D.H., Stendell, R.C., and Mulhern, B.M., 1979, Relations of wintering canvasbacks to environmental pollutants—Chesapeake Bay, Maryland: Wilson Bulletin, v. 91, no. 2, p. 279–287. [Also available at http://sora.unm.edu/node/129624.]

Wiemeyer, S.N., 1971, Reproductive success of Potomac River ospreys—1970: Chesapeake Science, v. 12, no. 4, p. 278–280. [Also available at http://www.jstor.org/stable/1350918.]

Wiemeyer, S.N., 1977, Reproductive success of Potomac River ospreys, 1971, *in* Ogden, J.C., ed., Transactions of the North American Osprey Research Conference , College of William and Mary, Williamsburg, VA, February 10–12, 1972: National Park Service, Transactions and Proceedings Series no. 2, p. 115–119. [Also available at https://archive.org/details/transactionsofno00ogde.]

Wiemeyer, S.N., Bunck, C.M., and Krynitsky, A.J., 1988, Organochlorine pesticides, polychlorinated biphenyls, and mercury in osprey eggs—1970–79—and their relationships to shell thinning and productivity: Archives of Environmental Contamination and Toxicology, v. 17, no. 6, p. 767–787. [Also available at http://dx.doi.org/10.1007/BF01061982.]

Wiemeyer, S.N., Bunck, C.M., and Stafford, C.J., 1993, Environmental contaminants in bald eagle eggs—1980–84—and further interpretations of relationships to productivity and shell thickness: Archives of Environmental Contamination and Toxicology, v. 24, no. 2, p. 213–227. [Also available at http://dx.doi.org/10.1007/BF01141351.]

Wiemeyer, S.N., Lamont, T.G., Bunck, C.M., Sindelar, C.R., Gramlich, F.J., Fraser, J.D., and Byrd, M.A., 1984, Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs—1969–79—and their relationships to shell thinning and reproduction: Archives of Environmental Contamination and Toxicology, v. 13, no. 5, p. 529–549. [Also available at http://dx.doi.org/10.1007/BF01056332.]

Wiemeyer, S.N., Lamont, T.G., and Locke L.N., 1980, Residues of environmental pollutants and necropsy data for eastern United States ospreys, 1964–1973: Estuaries, v. 3, no. 3, p. 155–167. [Also available at http://www.jstor.org/stable/1352065.]

Wiemeyer, S.N., Schmeling, S.K., and Anderson, Allen, 1987, Environmental pollutant and necropsy data for ospreys from the eastern United States, 1975–1982: Journal of Wildlife Diseases, v. 23, no. 2, p. 279–291. [Also available at http://dx.doi.org/10.7589/0090-3558-23.2.279.]

Wiemeyer, S.N., Spitzer, P.R., Krantz, W.C., Lamont, T.G., and Cromartie, Eugene, 1975, Effects of environmental pollutants on Connecticut and Maryland ospreys: Journal of Wildlife Management, v. 39, no. 1, p. 124–139. [Also available at http://dx.doi.org/10.2307/3800475.]

Yorks, A.L., 1999, Effects of polychlorinated biphenyls (PCBs) on reproduction, physiological processes, and biomarkers in tree swallows (*Tachycineta bicolor*): Baltimore, MD, University of Maryland, unpublished Ph.D. dissertation, 280 p. [Also available at http://hdl.handle.net/10713/1326.]

Overview of the Endangered Species Program

Glen Smart

In the late 1950s and early 1960s, we became increasingly aware, as a Nation, of declining populations of birds and mammals. Rates of extinction appeared to be skyrocketing and the situation was becoming critical. The country needed to take action to reverse this trend.

The Federal government began to show interest in the problem and acknowledged that it needed to intervene on a hands-on basis. The Washington, D.C., office of the U.S. Fish and Wildlife Service (USFWS) began to promote a program, championed by Dr. Ray Erickson, senior scientist at headquarters, to initiate captive research and propagation of birds and mammals. Research was needed to stabilize and recover populations in the wild. In order to save endangered species, the need was not only to raise birds and mammals in captivity but also to release them into the wild to augment populations.

Dr. Erickson envisioned a three-pronged program: a section of laboratory investigations; a section of propagation, whereby Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, would maintain captive populations of animals; and the field stations where field biologists would study the populations in the wild to determine what actions needed to be taken to reverse the downward trends.

Gene Knoder, a biologist with the USFWS stationed in Monte Vista Refuge in Colorado, began working with a captive population of sandhill cranes (*Grus canadensis*). Ray envisioned that they could be raised at Patuxent because we needed to work with a closely related or surrogate species whose population was much more abundant than that of the endangered whooping crane (*Grus americana*). Because most of these endangered species had rarely or never been bred in captivity, Patuxent researchers used the surrogates to develop techniques that were likely to be successful in the wild rather than to risk working directly with the endangered species.

The whooping crane was a rare species at that time in the mid-1960s, and, to the best of our knowledge, its population had been reduced to about 14 or 15 birds, although the exact number was disputed. Most of these birds wintered along the Gulf Coast of Texas and migrated to an unknown part of northern Alberta, Canada. In the early 1950s, a biologist returning from a forest fire saw a whooping crane with one offspring on the ground in Wood Buffalo National Park, which extends from northern Alberta into the Northwest Territories.

Through a cooperative effort with the Canadian Wildlife Service, the USFWS developed a program whereby we would remove one egg from each two-egg clutch and bring it into captivity, where the chicks could be hatched and reared; in this way, we could develop a captive breeding population.

The Endangered Species research team at its peak in early 1980s, at Snowden Hall, Patuxent Wildlife Research Center, Laurel, MD, 1980 (left to right, 1st row: Ray Erickson, Randy Perry, Paul Sykes, Mike Scott, John Serafin; 2nd row: Glen Smart, John Sincock, Noel Snyder, Sandy Wilbur; 3rd row: Jim Jacobi, Dave Mech, Dave Ellis, Scott Derrickson; 4th row: Barbara Nichols, Jim Carpenter, Cam Kepler; 5th row: Sharon Fox, Jim Wiley, Conrad Hillman; not present: George Gee, Gene Cowan). Photo by Paul Sykes, U.S. Fish and Wildlife Service.

Cranes commonly lay two eggs but, because of sibling rivalry and food availability, typically only a single chick is reared. Therefore, we were salvaging the egg that would theoretically be lost to sibling aggression or starvation.

Beginning in 1967, Ray and I traveled to Wood Buffalo National Park, near Fort Chipewyan, Alberta, to meet with Canadian Wildlife Service biologist Ernie Kuyt. He was a

Glen Smart (U.S. Fish and Wildlife Service), Ernie Kuyt (Canadian Wildlife Service), and Ray Erickson (U.S. Fish and Wildlife Service) with eggs, 1967. Photo by U.S. Fish and Wildlife Service.

delight to be around, and his knowledge of the area and his cooperative nature made him a valuable partner. Because only Ernie was authorized to leave the helicopter once we landed at a nest, it was his responsibility to collect the egg.

Before we could enter the park, of course, we had to have permits. Ray and I were issued permits to enter Wood Buffalo National Park, retrieve the eggs, and bring them out. The nesting area is about 80 percent water, consisting mostly of small, very shallow ponds. Most of them did not contain fish, as the ponds froze solid every winter. Many invertebrates did inhabit the ponds, however, and in this general area the cranes would nest and raise their young. The birds were typically very reluctant to leave the nest as Ernie neared them. On occasion, they even challenged the helicopter, which in itself was quite exciting.

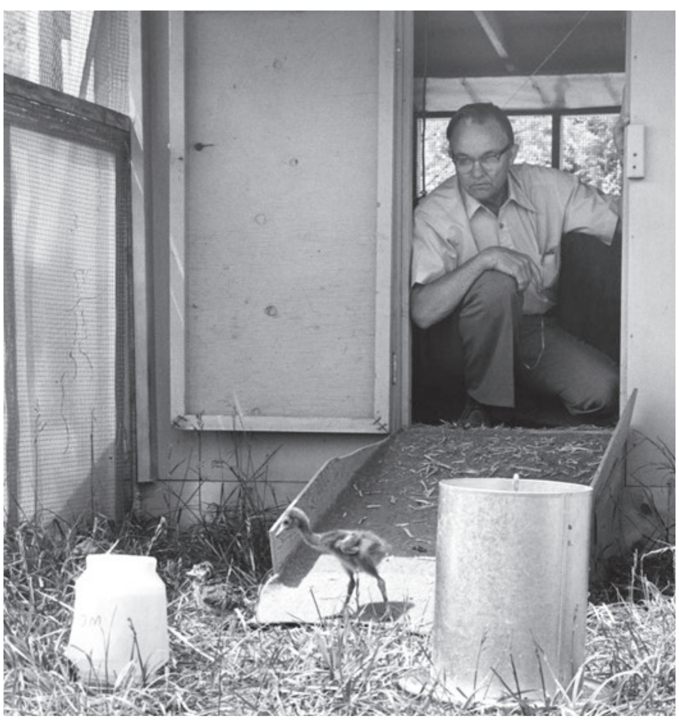
We had developed a 1-cubic-foot case made of Styrofoam with a cavity in the middle into which an egg could be placed. The plan was for Ernie to put the egg in this Styrofoam case and carry it out of the park. If he dropped the case, then, optimistically, the egg would not break or be damaged. Ernie looked at the case and said, "There's no way that I'm going to carry that thing back and forth." From then on, every egg that was collected from a nest at Wood Buffalo National Park was carried out in Ernie's old woolen sock! As far as I know, every egg that ever came out of Wood Buffalo National Park got a ride in Ernie's woolen sock, and, to my knowledge, he never dropped an egg. He would go out, examine the nest, photograph the nest, select the egg that he felt was less liable to hatch, collect the egg, and make his way back to the helicopter, where he would relinquish the egg to us. Ray and I maintained them in a portable incubator that we had brought with us.

Glen Smart and Ray Erickson (U.S. Fish and Wildlife Service) monitoring crane eggs, 1967. Photo by U.S. Fish and Wildlife Service.

In the first year (1967), we were going to be flown back to Maryland in an executive jet by the Canadian Wildlife Service, or by the Canadian Air Force. However, that was the year of the Six-Day War in the Middle East. U Thant, the Secretary General of the United Nations, took our plane that year, and we had to come back on a commercial flight. Thereafter, we returned in first-class accommodations with an executive jet each year.

The feather development of each chick was closely monitored at Patuxent. By November or December, a chick has molted its feathers from the mid-neck down through most of the body, but it still has a brown neck and brown wings, which are indicative of that time of the year. The birds have a continuous molt, so they continue to molt throughout the winter. By the time they fly north in the spring, the birds are completely white except for the brown head.

Another species we worked with in the 1960s was a small race of Canada goose (*Branta canadensis*) that breeds only in the Aleutian Islands off the coast of Alaska. At that time, they were called the Aleutian goose (*Branta hutchinsii leucopareia*). Their population had declined to such an extreme point that we thought they were extinct. This belief changed, however, when a refuge manager, Bob Jones (USFWS), made one of his lengthy trips into the outer Aleutians in an open dory. He was on Buldir Island, which is a relatively small pinnacle of rock about 5 × 8 miles in size, with very precipitous cliffs. He found a population of about 100 to 150 Aleutian geese breeding there.



Ray Erickson (U.S. Fish and Wildlife Service) and chick. Photo from the newspaper "Laurel Leader." Reprinted with permission from The Baltimore Sun. All rights reserved.

The Aleutian geese originally were quite common throughout the Aleutians. With the interest in fur coats and other fur clothing, the arctic fox (*Alopex lagopus*) furs were very valuable and desirable. The Russians fur trappers brought foxes to many of these islands, and subsequently the foxes reproduced. The trappers would come back at the appropriate times and harvest the foxes for furs—it was almost a captive fur-animal population. This population of foxes was extremely detrimental to the ground-nesting species of birds and other animals there. The Aleutian Canada goose was one of the most obvious of the birds and it was one of the first to disappear because of predation by the foxes. Fortunately for the birds, no foxes were brought to Buldir Island because of its precipitous cliffs; fortunately for us, one small area on the northern side of Buldir Island is relatively flat, allowing us access to the island. We traveled to the island and went ashore in late spring. We collected approximately 22 goslings that were newly hatched and brought them back to Patuxent to be part of our breeding population.

Aleutian Canada geese nest similarly to the other Canada geese. We raised many of these birds, but the problem then was how to release them back into the wild. In the 1960s, the Aleutian Islands National Wildlife Refuge staff was actively destroying the foxes on various islands. As an island would be cleared of foxes, we would transport some of these captive-reared geese to the island and release them, hoping that they would disperse and repopulate the island. Unfortunately, although the foxes were gone, there were still many bald eagles (*Haliaeetus leucocephalus*) remaining. Because eagles are fond of geese as a dinner item, that plan was less than successful.

We tried several alternatives. One solution that worked well, once the islands were cleared of foxes, was to go out to Buldir Island, capture an adult and the goslings that were with that adult, transport them to another island, and release them as a family unit. They would then mature, reproduce,

Crane flock manager Bruce Williams, U.S. Fish and Wildife Service, with young whooping crane, 1986. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

and eventually repopulate the island. Although this population was only about 100 to 150 geese when discovered by USFWS biologist Bob Jones, it now has skyrocketed to the more than 200,000 Aleutian Canada geese that are alive today (2016).

The Laboratory Investigations Program at Patuxent consisted of professionals in selected areas of expertise. These included many of the first people Ray hired, including a nutritionist, a physiologist, and a veterinarian to care for the birds in captivity and to cater to their every need. The field portion of the program was staffed originally with six biologists. Patuxent biologist Roy Tomlinson went to Arizona to study the masked bobwhite quail (*Colinus virginianus ridgwayi*), which is a desert form of bobwhite (*Colinus virginianus*) that was nearly destroyed. The remaining population was found mostly in Sonora, Mexico, with additional birds occupying a few valleys that extend into southern Arizona.

When cattle herds from Mexico were driven north to Tucson to the railheads, they destroyed most of the fragile grasslands, which are slow to recover. As a result, over time the habitats of the masked bobwhite quail in the United States were destroyed.

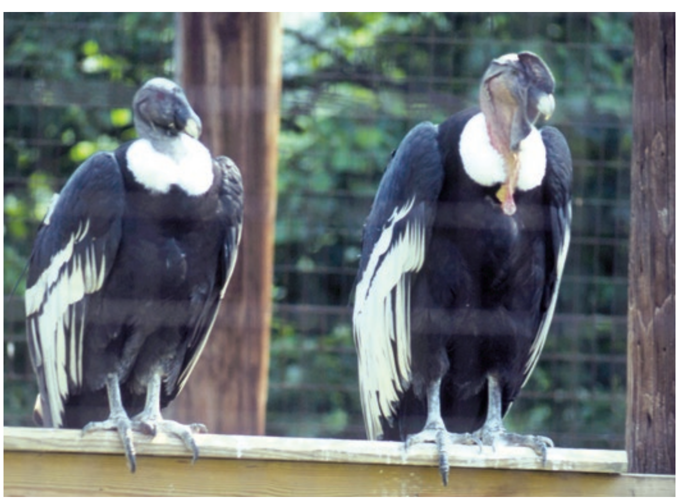
Roy conducted most of his work in Sonora. He developed a technique by which he would go into the desert and find a cactus wren (*Campylorhynchus brunneicapillus*) nest that he knew would be lined with feathers that the wrens obtain from the desert floor. Roy would examine the nest and identify bird species from the feathers that he found. If he found bobwhite quail feathers, of course, he would assume they were indicative of the presence of bobwhites in the area.

I went with him when we received the first bobwhites from two brothers in Tucson, Jim and Seymour Levy. They had been studying the birds on their own, and had a few birds in captivity. They let us have three or four pairs. We brought them to Patuxent and attempted to breed them. We were successful and got a number of eggs. The birds' fertility was quite low, however; the chicks were weak and so inbred that production was practically nil. Therefore, we needed to obtain some new birds to bolster that breeding population.

I went to northern Mexico with Roy; we trapped about 20 birds and brought them back to Patuxent. They proved easy to breed; we could literally breed them by the hundreds. We had no idea how to release them, however, so we began by simply placing them in a pen. We allowed them to remain there for a few days, where we fed and cared for them, and then we opened the door and let them walk out. This plan, unfortunately, was not successful because of the many hawks and other predators in the area. The bobwhites were quite uneducated in the ways of the wild, and, as a result, suffered substantial mortality.

Next, we paired neutering females from a captive Texas bobwhite quail population with male masked bobwhites so they would not hybridize. As chicks hatched in the incubator, we would put 12 to 15 with one of these pairs, take them to the desert, and release them. Again, results were similar to those of the earlier releases, but with one exception: the mesh on the pens was large enough that the babies could get out and begin to forage a little on their own, but the parents would always call them back. We would keep them there for a week or so, until they became familiar with the area, and then release them. We did build a stable population for a while but, because of the inadequate habitat, I do not think that population has been very successful. I believe there are still a few quail in Arizona and a few in Sonora.

The California condor (*Gymnogyps californianus*) population was 12 or 13 birds, and the appropriate course of action regarding the species was a very controversial subject in the area of their native habitat. One faction of biologists felt very strongly that we should leave the birds alone to die in dignity,



Andean condor pair in captive breeding pen at Patuxent Wildlife Research Center, Laurel, MD. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Andean condors with backpack transmitters, Patuxent Wildlife Research Center, Laurel, MD. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

and not bring them into captivity, where they would be no longer condors at all, but similar to captive chickens. The other faction felt that, in order to save them, we needed to bring all condors into captivity, breed them, and eventually release them back into the wild.

When the population began to decline precipitously, the State of California indicated that Patuxent could catch all of the birds and bring them into captivity. However, no California condors were allowed to leave the State of California. Unfortunately, then, we were not able to bring them back to Patuxent.

However, we were able to reach a compromise with the San Diego Zoo and the Los Angeles Zoo. The zoos built facilities that were off exhibit to the public and began to raise California condors. At Patuxent, we were studying the closely related Andean condor (*Vultur gryphus*). We found that by removing eggs as they were laid, we could obtain multiple clutches in a given year (a clutch being one egg in condors). Typically, we would get three or four eggs from a female, but I believe we once got as many as nine. By removing eggs, we could greatly increase the productivity of a given condor pair. Snyder (2016) discusses the details of this negotiation on the fate of the condors in depth.

The black-footed ferret (*Mustela nigripes*) was another animal we studied at Patuxent, but we had little success with it. Because of other priorities, we reduced the effort we were investing in this program, and it was eventually taken over by a consortium of State wildlife agencies and zoos with the guidance of the USFWS. Thousands of captive-raised black-footed ferrets have been released in eight western states, and also in parts of Canada and Mexico (National Black-Footed Ferret Conservation Center, n.d.; U.S. Fish and Wildlife Service, 2015).

Hawaii was home to a multitude of endangered species. Many of them were forest birds, including the Hawaiian crow (*Corvus hawaiiensis*), which was rare. John Sincock was the first biologist hired by Patuxent for that program. He began studying this and a variety of other species. The Hawaiian research program was difficult to conduct because of the terrain, but the researchers involved made great progress in the conservation of endangered species on the islands (Scott and Kepler, 2016).

Noel Snyder was the first Patuxent biologist to work on the Puerto Rican parrot (*Amazona vittata*) in Puerto Rico. This bird's population was very low—fewer than 20. We worked with this species briefly at Patuxent, after which Region 4 of the U.S. Fish and Wildlife Service and the Commonwealth of Puerto Rico became involved and set up a captive breeding population and facilities in Puerto Rico. They are doing well with them and in 2011 had about 500 birds, either in captivity or in one of two wild populations.

One of the first things that we found to be a limiting factor for the parrot was the curved-bill thrasher (*Margarops fuscatus*). The thrashers would go into the parrot nesting cavities, pierce the eggs, throw them out, and then use the nest site themselves. Dr. James Wiley, Patuxent (Wiley, 2016), presents a more detailed discussion of the Puerto Rican parrot research project.

Patuxent researcher Paul Sykes worked on snail kites (*Rostrhamus sociabilis*) and dusky seaside sparrows (*Ammodramus maritimus nigrescens*) in Florida. Snail kites feed almost exclusively on the apple snail. The kite population is currently (2016) doing well. Unfortunately, the dusky seaside sparrows did not fare as well, and actually became extinct during the period when Paul was working on them.

Paul Sykes is also well known for his studies with other endangered species, including the Kirtland's warbler (*Setophaga kirtlandii*) and the ivory-billed woodpecker (*Campephilus principalis*). A study of the Kirtland's warbler was initiated in 1985 on the bird's wintering grounds in the Bahamas, West Indies, as part of Patuxent's Endangered Wildlife Research Program. On the morning of February 26, Sykes and Paul Sievert captured an adult male Kirtland's warbler in a mist net

Paul Sykes, U.S. Fish and Wildlife Service, with a recently banded Kirtland's warbler, Eleuthera, Bahamas, West Indies, 1985. Photo by Paul Sievert, U.S. Fish and Wildlife Service.

Wolf with collar-mounted transmitter being tracked by David Mech, U.S. Fish and Wildlife Service, in Minnesota. Photo by U.S. Fish and Wildlife Service.

in a patch of low, dense shrub/scrub dominated by buttonsage (*Lantana involucrata*). The site was 1.3 miles north of the town of Governor's Harbour in the middle of the island of Eleuthera. The warbler was uniquely color banded and various morphological data were recorded, but in the excitement it managed to get free before it was photographed. Sykes named the bird "The Governor" for the proximity of its winter territory to Governor's Harbour. The warbler was recaptured at the same locality on February 28 and photographs were taken, including the one shown here, with the warbler being firmly held by Sykes. To the best of our knowledge, this was the first time a live Kirtland's warbler was photographed in the Bahamas, and at that time it was only the second banding of the species in the islands.

Dr. David Mech studied gray wolves (*Canis lupus*) in northern Minnesota and Michigan. Dave was a student at Purdue University when he studied wolves on Isle Royale in Michigan. He became very well known because of his studies, and subsequently was hired by the USFWS as the field biologist to study this population. Dave has been working with these animals since the early 1960s, and continues to work on wolves in that area. He presents major aspects of his studies together with supporting data in the chapter titled "Patuxent's Long-Term Research on Wolves," farther on in this report (Mech, 2016).

References Cited

Mech, L.D., 2016, Patuxent's long-term research on wolves, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 197–212. [Also available at https://doi.org/10.3133/cir1422.]

National Black-Footed Ferret Conservation Center, n.d., Black-footed ferret connections at blackfootedferret.org—Captive breeding, accessed June 3, 2016, at http://blackfootedferret.org/captive-breeding/.

Scott, J.M., and Kepler, C.B., 2016, Endangered species research in Hawaii—The early years (1965–87), *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 183–196. [Also available at https://doi.org/10.3133/cir1422.]

Snyder, N.F.R., 2016, Conserving California condors in the 1980s, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 147–156. [Also available at https://doi.org/10.3133/cir1422.]

U.S. Fish and Wildlife Service, 2015, Black-footed ferret—*Mustela nigripes*: U.S. Fish and Wildlife Service fact sheet, Region 6 (Mountain-Prairie Region), accessed June 3, 2016, at https://www.fws.gov/mountain-prairie/factsheets/Black-Footed-Ferret.pdf.

Wiley, J.W., 2016, Endangered species research in the Caribbean, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 157–170. [Also available at https://doi.org/10.3133/cir1422.]

Conserving California Condors in the 1980s

Noel F.R. Snyder

By the late 1970s, the California condor (*Gymnogyps californianus*) was in serious trouble, with probably no more than about 30 birds left in existence, all in a mountainous region just north of Los Angeles that is vegetated mainly in chaparral and grasslands. All estimates of population size and trends offered since the early condor studies by Carl Koford in the 1930s and 1940s indicated a continuing decline toward extinction, and it appeared that few years were left before the species would be gone (see Koford, 1953; Wilbur, 1978). Evidently, the conservation steps that had been taken, including the creation of a number of important condor reserves, were not resulting in recovery of the species.

Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, had been involved in studies of the species since the mid-1960s, beginning with the efforts of Fred Sibley from 1966 to 1969 and continuing with the work of Sanford Wilbur through the 1970s (Sibley, 1968; Wilbur, 1978). The causes of the decline remained controversial and difficult to resolve, however, because of the enormous practical difficulties involved in studying such a rare and highly mobile species in exceedingly rugged terrain, especially when research was limited by political constraints to passive, nonintensive techniques and funding for research was minimal.

By 1980, no functioning captive population of California condors was yet in existence, largely because of the consistent opposition of biologist Carl Koford and other early researchers of the species, who believed a captive flock would represent an abandonment of efforts to conserve the wild population. Nevertheless, Patuxent had established a surrogate captive population of Andean condors (*Vultur gryphus*) in anticipation of a need for captive breeding of the California species and had been successful in demonstrating routine capacities of the Andean birds to lay replacement eggs—thus greatly increasing their reproductive potential under intensive management (see Erickson and Carpenter, 1983).

California condor, Ventura County, CA, 1980s. Photo by David Clendenen, U.S. Fish and Wildlife Service.

Fortunately, two outside evaluations of the recovery program were conducted in 1978—one by Jared Verner of the U.S. Forest Service and one by a combined Audubon-American Ornithologists' Union panel chaired by Robert Ricklefs of the University of Pennsylvania (Verner, 1978; Ricklefs, 1978). Both evaluations strongly recommended the initiation of intensive research and management techniques such as radiotelemetry and captive breeding. These reports were crucial in mobilizing the National Audubon Society to mount a lobbying effort with Congress that resulted in the creation in 1979 of a well-funded, final intensive program on behalf of the condor.

On-the-ground operations of the new program were initiated in 1980 and were led by Patuxent in collaboration with the National Audubon Society, but there were many other cooperators, including the California Department of Fish and Game, the U.S. Forest Service, the Bureau of Land Management (BLM), the Los Angeles and San Diego Zoos, and several California universities and research institutions.

Sespe Condor Sanctuary, Ventura County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

My personal involvement in condor research began at this point as field leader of Patuxent's condor program; John Ogden became the principal leader of National Audubon's field efforts. In this presentation, I briefly review the cooperative studies that were conducted in the 1980s to identify the primary causes of decline of the wild population and the cooperative efforts to create a viable captive population, as well as certain aspects of subsequent releases of captives to the wild—subjects covered in more detail in Snyder and Snyder (2000, 2005) and Snyder (2007).

Research on Causes of Decline in the 1980s

At the start of the new intensive program in 1980, there were three primary competing hypotheses under consideration regarding the main cause of the decline of the California condor. The first was the position of Miller and the McMillan brothers (1965), who had studied the species in the early 1960s and believed that the bird was breeding normally, but was suffering from overwhelming mortality stress from illegal shooting and from poisoning campaigns, especially ground squirrel poisoning using Compound 1080 (an organofluorine pesticide). The second hypothesis was the proposal of Wilbur (1978) that the species was suffering from declining carrion food supplies and had largely stopped breeding, with only two pairs still known to be actively reproducing in the late 1970s. The third hypothesis was that of Kiff and others (1979) that the condor was suffering major stress from dichlorodiphenyldichloroethylene (DDE) contamination of its food supplies, which apparently had caused a more than 30-percent decline in eggshell thickness in the 1960s and could still be causing reproductive effects such as frequent egg breakage and lowered reproductive output.

All three of these hypotheses were plausible, but all suffered from only fragmentary supporting evidence and none was fully persuasive, though there was special concern about the potential effects of DDE, as the extent of eggshell thinning apparently had been severe in the 1960s. To resolve which factors were truly responsible for the condor's continuing decline, so that conservation could proceed intelligently, comprehensive studies of contaminant levels, breeding productivity, mortality rates, and causes of mortality in the wild population were needed. In pursuit of these goals, diverse research activities were planned, many of them aided by radiotelemetry.

Intensive basic biological studies were especially crucial at this stage because it was not clear that all potentially important causes of the decline had been identified. One source of mortality that was not recognized by Koford, Miller, and the McMillans, or by any other historical condor researcher, was lead poisoning resulting from the birds' ingestion of ammunition fragments in hunter-shot carcasses. Locke and others (1969) at Patuxent had published a paper on a captive Andean condor dying from feeding on an ammunition-contaminated carcass, and there was every reason to suspect frequent exposure of California condors to lead-contaminated carcasses because of the large amount of hunting going on in the State. Unless a substantial number of condors could be radiotagged so that dead birds could be found promptly and comprehensively necropsied, it could be difficult to determine the severity of the threat of lead poisoning.

Crucial to evaluating all hypotheses was the development of improved methods of censusing the wild population. From 1965 until 1980, estimates of the size of the condor population were based largely on the annual simultaneous October Survey during which people were stationed at overlooks of known condor concentration areas throughout the range (see Mallette and Borneman, 1966). This methodology was relatively crude because of difficulties involved in recognizing and eliminating duplicate sightings of birds that moved from one observation point to another and because only a modest fraction of the range of the species was covered by accessible observation points. Program cooperators initially anticipated that if many of the birds in the wild population could be radio-tagged, the uncertainties in future October Surveys could be substantially reduced. Instead, a more reliable and informative method of censusing evolved through the extensive use of a less advanced technology—photography of flying birds (see Snyder and Johnson, 1985). Early success with this new photographic method led to abandonment of the October Survey after 1981.

Each individual condor was discovered to be unique in its flight feather pattern as a result of unique feather damage events and highly variable molt of feathers (Snyder and others, 1987). Because feather patterns changed only slowly through time, when a sufficient number of photos of flying condors had been taken throughout the condor range, all individuals could be continuously recognized and counted. The photos were sorted chronologically into files representing the histories of individual birds—histories that revealed not only the movements of the birds but also how many birds were present on specific dates. Much of the credit for this effort goes to Eric

California condor with distinctive feather damage and molt, southwestern California, 1980s. Photo by Jesse Grantham, U.S. Fish and Wildlife Service.

Noel F.R. Snyder (left), U.S. Fish and Wildlife Service, and Eric Johnson, California Polytechnic State University, San Luis Obispo, CA, sorting condor photos. 1982. Photo by Helen A. Snyder, U.S. Fish and Wildlife Service.

Johnson and his students at California Polytechnic State University in San Luis Obispo, but essentially everyone involved in studying condors contributed to its success. By 1982, it was possible for the first time to census the wild population accurately and continuously.

The photographic censusing revealed a very rapid decline in the remnant population associated with very high mortality rates. From late 1982 to mid-1985, the population decreased in annual decrements from 21 to 19 to 15 to 9 known individuals, and the average annual mortality rate for the population was more than 25 percent per year, a rate far greater than any that could allow population stability or growth under known or potential reproductive rates (see Meretsky and others, 2000). Such figures clearly indicated a grave crisis in survival of the wild population irrespective of any potential reproductive problems. Unexpectedly, the mortality rate was slightly higher in full adults (26.8 percent) than in immatures (22.2 percent), a finding that was important in identifying potential causes of decline, as discussed below.

While photographic censusing was underway, a major effort also was made to find all nests in the wild population and to directly track their rates of success and causes of failure. To this end, a staff of nest observers was assembled that grew to 12 individuals by the time the program was several years old. All nesting pairs were eventually located and studied on a continuing basis despite major logistical difficulties.

Most condor nests were caves in cliffs, but one active study site was discovered in a burned-out hollow of a giant sequoia. Nests were generally hard to find because the breeding pairs were dispersed over an extensive and rugged terrain and visited their nests infrequently. To find active nests of pairs that were not radiotagged, we employed multiday vigils at strategic lookout points within potential nesting areas, following the movements of prospective nesting birds through telescopes, looking for aerial signs of nesting behavior, and then gradually homing in on the locations of nests. Once active nests had been located, they were given steady daylight coverage from distant observation points until the young fledged or the nests failed. Twenty-three of the 25 active nests found during studies in the 1980s were sites that had not been previously documented as condor nests by earlier researchers, but most of these nests were internally plastered with excrement layers, indicating repeated use in earlier years rather than new nests.

As summarized in Snyder and Snyder (2000, 2005), the studies of breeding biology in the 1980s resulted in the following major conclusions:

1. Most adults were paired and were breeders, although two of the pairs found were likely pairs of homosexual males that had nest sites but laid no eggs. These pairs likely resulted from the existence of a slightly skewed sex ratio among adults. Other than these two pairs, there were no generic signs of a failure of adults to breed, and all clearly heterosexual adult pairs were breeding consistently except when burdened with dependent fledglings. Even when the total population of condors in the wild, including immatures, had declined to just 15 individuals in 1984, five

Condor nest in giant sequoia, Ventura County, CA, 1984. Photo by Helen A. Snyder, U.S. Fish and Wildlife Service.

Observation point for locating condor nests in Sespe Condor Sanctuary, Ventura County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Pair flight display of California condors, southwestern California, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

pairs of condors—two-thirds of the population—were still actively breeding.

2. Nesting efforts were reasonably successful, resulting in fledglings in nearly half the nesting attempts, a rate similar to those documented for other solitary nesting vultures. Nestlings were consistently well fed, and the survival rate of nestlings to fledging was high. Most nest failures occurred at the egg stage.

3. Clutch size was invariably a single egg, and nesting pairs readily laid replacement eggs when early-laid eggs failed as a result of predation or were taken into captivity.

4. Pairs that produced a fledgling in one year were capable of breeding late in the next spring, but then typically skipped breeding in the third year while they still were tending a dependent fledgling from late in the second year. Thus, successful pairs were evidently capable of producing two young in 3 years.

5. The primary cause of the moderate number of nesting failures was predation by common ravens (*Corvus corax*) on eggs. There were no persuasive signs of reproductive failure to DDE contamination, such as chronic egg breakage unrelated to raven predation. Neither was there any evidence of chronic failure of eggs to hatch after full-term incubation. As documented in Snyder and Meretsky (2003), the correlation between eggshell thickness and DDE levels in eggshell membranes was weak; instead, eggshell thickness was highly correlated with egg size, indicating that the thin eggshell fragments collected in the 1960s could have come from relatively small eggs rather than from structurally weak eggs. One female in the 1980s was laying eggs whose shell thickness was nearly 25 percent less than the historical mean, but her eggs were also very small and she was the most successful female of her period in producing fledglings. Her eggshells were of an appropriate thickness for the size of her eggs, and there is no good evidence that she suffered from structurally weak eggs. The apparently severe shell thinning of the 1960s could have been largely an artifact of small egg size in the few females sampled, which may well have included the small-egged female studied in the 1980s. Unfortunately, egg size was not documented for any of the eggs in the 1960s but, consistent with egg size being the primary determinant of shell thickness, nesting success in the 1960s, as documented by Fred Sibley (1968) and in a later analysis by Snyder (1983), was not distinguishable from nesting success in the 1980s, and was reasonably strong.

Therefore, the intensive studies of the 1980s yielded no clear evidence of major breeding problems due to food stress, DDE contamination, nest predation, or any other factors, but instead indicated that excessive mortality of free-flying adults and immatures was the primary cause of population decline. Moreover, judging from the eight dark-headed immatures (about one-third of the population) whose existence we were fortuitously able to document at the start of the intensive program, there had been no major problems with reproduction at least as far back as the late 1970s.

The intensive studies of the 1980s, therefore, were most supportive of the hypothesis of Miller and others (1965) that the primary problems of the species were mortality factors, not reproductive factors (Wilbur, 2004). However, accumulating evidence (Snyder, 2007) indicated that the single most important mortality factor was not shooting or the sorts of poisoning described by these researchers, but was instead the kind of poisoning we had feared might be of primary importance as described by Locke and his collaborators in 1969—lead poisoning (Locke and others, 1969; Snyder and Snyder, 2000, 2005; Snyder, 2007).

Probably just as a result of chance, the condors we were able to radiotag in the 1980s had much better survival rates than the condors that were not radiotagged, so that relatively few dead condors were recovered for necropsy, and information on specific mortality factors was accumulated only slowly. Nevertheless, of the four free-flying condors that were recovered dead or dying in the 1980s, three were found to be victims of lead poisoning. The fourth was a victim of cyanide poisoning, presumably from a coyote trap. Poisoning from contaminated food is one of the few causes of mortality that can be expected to affect adults as severely as immatures and, therefore, it provides a plausible explanation for the nearly identical mortality rates found for these age classes in the 1980s. In contrast, if the population had been suffering mainly from shooting or collision mortality, one would have expected the mortality rate of relatively unwary and clumsy immatures to greatly exceed that of adults–a situation found in populations of many large raptorial birds.

When the first well-documented case of lead poisoning occurred in 1984, there was not yet nearly enough evidence to conclude that lead might be the most important cause of

John Schmitt, U.S. Fish and Wildlife Service, with lead-poisoned condor, 1980s. Photo by Helen A. Snyder, U.S. Fish and Wildlife Service.

the species' decline. However, when two more condors were diagnosed as victims of lead poisoning in the next 1-1/2 years and a full 40 percent of the wild population was lost over the winter of 1984–85, a belief that the species might be in deep trouble from this source became tenable, first for the California Fish and Game Commission and ultimately for the U.S. Fish and Wildlife Service (USFWS). This belief was the major force that led both agencies to decide that the last remaining wild condors should be brought into captivity—an action that was accomplished by early 1987.

The problem of lead poisoning from ammunition fragments remains unsolved today (2016) despite the accumulation of supporting data indicating that lead poisoning from ammunitions has been a major problem for the condor, as well as for other wildlife species such as swans and eagles (see discussion in Snyder [2007]).

The supporting data for condor lead poisonings have come from ongoing releases of captive condors to the wild that have been conducted since the early 1990s (Jane Hendron, U.S. Fish and Wildlife Service, unpub. report, 1998; Snyder and Snyder, 1989, 2000). These releases have been followed by many lead-poisoning mortalities plus many more near-mortalities from lead poisoning that have been countered by returning birds to captivity for emergency chelation treatment. One can question why releases have been attempted in the absence of mitigation or removal of the main cause of extirpation, but in any event they have confirmed beyond reasonable doubt that lead poisoning continues to be the major threat to wild populations. The release program in Arizona alone has performed considerably more than 150 emergency chelations of lead-poisoned birds since releases began in 1996 (see Walters and others [2010]). In spite of such rescue efforts, however, lead poisoning remains the principal source of mortality in the release programs (see Finkelstein and others [2012], Rideout and others [2012]).

Formation of a Captive Flock

Formation of a captive flock of condors involved capturing wild condors from the egg stage to the adult stage. This process faced opposition from individuals and some conservation organizations, as described in detail by Wilbur (2004) and Syder and Snyder (2000, 2005). The process could have been completed with only minimal effects on the wild population if it had been started early enough and had been limited to collecting eggs early in the breeding season, leaving time for pairs to recycle with replacement eggs (Snyder and Snyder, 2000, 2005). A captive flock was established at the Los Angeles Zoo in 1982, and only about half the captive flock was taken as eggs. The remainder consisted of nestlings and free-flying birds trapped from the wild, after it became clear that the wild population was inviable and about to disappear completely.

At the start of the intensive program, the California condor had never been bred in captivity and no members of the species were in confinement except Topatopa, a wild male fledgling that had come into the Los Angeles Zoo with an injured foot in 1967. Unfortunately, taking eggs from the wild population was politically impossible until 1983. Replacement egg-laying was well known for captive Andean condors by the start of the intensive program, but, because at that time such layings had not been clearly documented in the California condor permit, clearance to use this approach could not be secured from State and Federal authorities, although it seemed likely that California condors would have the same capacities.

Instead, the captive acquisition program was initially limited by permit restrictions to obtaining an unpaired female bird to pair with Topatopa, the only California condor already in captivity. This was a dubious strategy at best because a captive population consisting of one pair was far from adequate to sustain or significantly bolster the species and because Topatopa was known to be a behaviorally compromised bird. Topatopa had been held in isolation from his species since the late 1960s, and his potential for breeding was highly questionable because of his strong orientation to humans. Further, identifying an unpaired female in the wild population and capturing her posed some strong practical difficulties at that time, as condors cannot be sexed externally and were not yet individually identifiable. Efforts to obtain a potential mate for Topatopa were fruitless during the first 3 years of the intensive program.

Fortunately, the intensive observations of nesting pairs in 1982 allowed conclusive documentation of a case of natural replacement clutching in the wild, eliminating the roadblock to forming a captive flock from eggs. Proof of natural replacement clutching was arguably the most important and beneficial result of the intensive nesting studies of the 1980s. It now became possible to take eggs from all breeding pairs in the wild and to artificially incubate them at the San Diego Zoo, while the pairs recycled with replacement eggs in the wild. In the first year of operations—1983—four eggs were taken from three pairs and all hatched successfully, producing four surviving young. Together with two chicks produced in the wild, six young were produced that year, in contrast to the typical average of two young produced in previous years. Results were even better in 1984, when five pairs produced seven surviving young. Thus, the removal of eggs for artificial incubation demonstrably increased overall reproduction of the remaining wild birds largely through replacement layings. Indeed, all pairs but one ultimately demonstrated a potential for double clutching within a single breeding season; three pairs even demonstrated a capacity for triple clutching (see Snyder and Hamber [1985]).

Thus, by late 1984, a captive flock was being rapidly assembled, and a consensus developed that in the following year the taking of eggs should continue, but that it might be possible to channel some of the production possible with replacement clutching into sustaining the wild population with an early release program. This hope was based on an assumption of reasonably good survival of the existing wild breeding pairs. The recovery team developed a plan approved by all cooperators in the program by which a pair would begin to contribute to a release program once five progeny had been obtained from the pair for permanent holding in the captive flock. By late 1984, two pairs were each represented by five progeny in captivity, so it appeared that both these pairs could produce young for a release program starting in 1985 if they survived to the 1985 breeding season. At that point, causes and rates of decline for the wild population were still not well established, and there was every reason to continue to attempt to maintain the wild population. Most program participants were looking forward to splitting the benefits of replacement clutching between the wild and captive populations in 1985.

Unfortunately, mortality of breeding pairs proved catastrophic over the winter of 1984–85, and only one of the five pairs active in 1984 survived to lay eggs in 1985. This was not one of the pairs with five progeny in captivity. Moreover, of the 15 birds in the wild population in late 1984, only 9 were still alive by mid-1985—a 40-percent decline in the wild population in just a few months. This extremely high mortality was observed mostly in birds that were never recovered, so causes of mortality were for the most part unknown, although one of the lost birds was recovered moribund and was determined to be another victim of lead poisoning. The failure of the assumptions underlying an early release program to hold true during the winter of l984–85 led to one of the most contentious periods of debate over strategies in the history of the condor program.

On one side of the debate were those who, like me, believed that it was wisest and most conservative to conclude from recent events that the wild population was truly inviable and that release of captives into such a population would actually decrease the chances of ultimate recovery of the species by compromising the viability of the captive population. It appeared that lead poisoning could, in fact, be the major problem and that any hope that this problem could be reversed before the species became extinct in the wild was unrealistic. Meanwhile, the captive flock was neither large enough nor genetically diverse enough to ensure viability—at that time it was made up almost entirely of the progeny of a few pairs. Capturing the last free-flying birds might at least achieve a viable captive population and allow time to correct the lead problem, whereas leaving them in the wild would almost certainly be to watch them, and possibly the species, perish quickly with no long-term benefit. The California Fish and Game Commission opposed both releases and leaving birds in the wild (see discussion in Snyder and Snyder [2005]).

On the other side of the debate were people and organizations that argued that the recent high mortality was likely atypical and that it was crucial to maintain the wild population as long as possible by proceeding with releases even though the minimal conditions established by the recovery team for releases could not be met. Without birds in the wild, it was argued, it would not be possible to maintain existing and prospective condor reserves or funding for a continuing condor program (Wilbur, 2004).

The opposing points of view resulted in a stalemate through much of 1985. No releases were conducted because they required approval at both the Federal and State levels, which was not obtainable. The only action agreed upon through extensive negotiation was that three of the remaining nine birds in the wild could be brought into captivity. These three birds were trapped into captivity in the summer of 1985.

The position of the recovery team on capture of the last wild birds was initially ambivalent, although in early 1985 the team quickly reached a consensus that releases should not be initiated. However, by the summer of 1985, the team recommended that at least three of the remaining six wild birds should be taken captive, and by the fall of 1985, the team was in full agreement with the State of California's preferred position that all wild birds should be taken captive. This agreement developed in part because of a vigorous debate on the issue held at the International Vulture Symposium in Sacramento in November of that year.

Then, in early December 1985, the USFWS reversed its position and the long debate was finally resolved with a consensus of the USFWS with the State of California and the recovery team that all wild birds should be taken captive and that no near-term releases should be conducted (Snyder and Snyder, 2000, 2005). This agreement clearly came about because another condor still in the wild contracted terminal lead poisoning at this point, making it increasingly plausible that the major problem in the wild was indeed lead poisoning, a very difficult problem to solve quickly.

However, agreement that the last birds should come into captivity still had to clear two more hurdles: (1) a lawsuit filed by the National Audubon Society to prevent trapping of the last wild birds, and (2) objections to trapping the last wild birds from a group of Native Americans. The lawsuit and Native American objections were successfully resolved by mid-1986, and the last birds were trapped into captivity by early 1987, yielding an initial captive flock of 27 birds, consisting of 13 males and 14 females (Snyder and Snyder, 2000, 2005).

As hoped, the California condor proved adaptable to captive conditions and has bred readily in confinement, with all birds initially taken captive eventually becoming captive breeders—even Topatopa, although he was one of the very last to begin reproduction. The number of condors currently in existence now totals near 400, about half of them in the wild and half in captivity. This total is far greater than the low point of 22 individuals reached in 1982 before a captive program was launched (Snyder and Snyder, 2005).

Releases and Prospects for Viable Wild Populations

Following the rapid success in captive breeding, releases to the wild were begun in the early 1990s, first in southern California, then later in Arizona, other locations in California, and Baja California. Unfortunately, like the historical wild population in the 20th century, none of these populations has yet achieved viability, even with intensive management. Problems have been diverse but, as discussed above and in Snyder (2007), Walters and others (2010), Rideout and others (2012), and Finkelstein and others (2012), lead poisoning soon emerged again to dominate the list of negative factors. These authors agree that viable, self-sustaining wild populations likely will never be achieved unless the lead poisoning threat is fully addressed.

Other than a long-standing ban on lead shot in waterfowl hunting, lead ammunitions have not been banned anywhere in the United States except in the condor range in California, where a ban was instituted in 2007 and expanded in 2013. Elsewhere, prospective bans face continuing political opposition from interest groups fearful of potential consequences (see discussion in Snyder [2007]).

As was widely anticipated, the California ban on lead ammunitions, though an important step symbolically, has not ended condor lead poisonings in the State, perhaps because lead ammunitions are still readily obtainable in other parts of the country. Lead poisoning may continue if the supply of lead ammunitions is not fully removed

In favoring a ban on the use of lead ammunitions, most condor conservationists have not sought the end of hunting activities, but only the end of hunting activities using toxic ammunitions. In fact, hunting activities, so long as they are conducted with nontoxic ammunitions, may prove to be crucially beneficial for condor conservation in many regions by providing an adequate long-term carrion food supply (Snyder and Snyder, 2000, 2005).

Final Remarks

Although a major threat, lead poisoning is not the only source of the excessive mortality of wild California condors, and excessive mortality is not the only problem associated with releases. Discussions of other threats to the species are found in Mee and Hall (2007) and Walters and others (2010). The release population along the central California coast, for

Condor release site, Sespe Sanctuary, Ventura County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

example, has recently been experiencing reproductive problems that are reflected in low hatchability of eggs (Burnett and others, 2013). Causes of the low hatchability have not been identified conclusively, although there are concerns that it may stem from these birds feeding heavily on carcasses of marine mammals, which are known to carry high levels of many contaminants (Marine Mammal Commission, 1999). Which contaminant might be involved is as yet unclear.

Another problem that is currently being vigorously debated is the need to ensure the future existence of optimal foraging regions for the species (Snyder and Snyder, 2005). Nesting habitats of the condor are mostly well-protected National Forest lands, but foraging habitats are largely private ranchlands that are being progressively lost to development. Arguably, the most important foraging region for the historical wild population and for the release population in southern California lies on the Tejon Ranch in Kern County, CA, parts of which were designated Critical Habitat for the species by the USFWS in 1976. The Tejon Ranch owners are now (2016) proposing major housing developments that would directly compromise a substantial portion of this Critical Habitat (Snyder and Snyder, 2005, p. 175). These development plans, if implemented, could have major adverse effects on the species.

Altogether, the condor program was one of the longest and most arduous efforts in Patuxent's Endangered Wildlife Research Program. That the condor is still with us is a great credit to the USFWS, and although wild populations of the species are not yet self-sustaining, there is reason to hope that this goal can be reached if the commitment shown by involved agencies in the past can be sustained, and the remaining obstacles to full recovery can be successfully addressed.

References Cited

Burnett, L.J., Sorenson, K.J., Brandt, Joseph, Sandhaus, E.A., Ciani, Deborah, Clark, Michael, David, Chandra, Theule, Jenny, Kasielke, Susie, and Risebrough, R.W., 2013, Eggshell thinning and depressed hatching success of California condors reintroduced to central California: Condor, v. 115, no. 3, p. 477–491. [Also available at http://dx.doi.org/10.1525/cond.2013.110150.]

Erickson, R.C., and Carpenter, J.W., 1983, Captive condor propagation and recommended release procedures, *in* Wilbur, S.R., and Jackson, J.A., eds., Vulture biology and management: Berkeley, CA, University of California Press, p. 385–399.

Finkelstein, M.E., Doak, D.F., George, Daniel, Burnett, Joe, Brandt, Joseph, Church, Molly, Grantham, Jesse, and Smith, D.R., 2012, Lead poisoning and the deceptive recovery of the critically endangered California condor: Proceedings of the National Academy of Sciences of the United States of America, v. 109, no. 28, p. 11449–11454. [Also available at http://dx.doi.org/10.1073/pnas.1203141109.]

Kiff, L.F., Peakall, D.B., and Wilbur, S.R., 1979, Recent changes in California condor eggshells: Condor, v. 81, no. 2, p. 166–172. [Also available at https://sora.unm.edu/node/102945.

Koford, C.B., 1953, The California condor: National Audubon Society Research Report, no. 4, New York, National Audubon Society, 154 p.

Condor foraging area, Tejon Ranch, Kern County, CA, 1980s. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Locke, L.N., Bagley, G.E., Fricke, D.N., and Young, L.T., 1969, Lead poisoning and aspergillosis in an Andean condor: Journal of the American Veterinary Medical Association, v. 155, no. 7, p. 1052–1056. [Also available at http://www.cabdirect.org/abstracts/19721300469.html;jsessionid=4C0E8F4F6FE033F53E11C80F2BAE0E35.]

Mallette, R.D., and Borneman, J.C., 1966, First cooperative survey of the California condor: California Fish and Game, v. 52, no. 3, p. 185–203.

O'Shea, T.J., Reeves, R.R., and Long, A.K., eds., 1999, Marine mammals and persistent ocean contaminants: Bethesda, MD, Marine Mammal Commission, Proceedings of the Marine Mammal Commission Workshop, Keystone, CO, October 12–15, 1998, 150 p. [Also available at http://www.mmc.gov/wp-content/uploads/contaminantsreport.pdf.]

Mee, Allan, and Hall, L.S., eds., 2007, California condors in the 21st century: Series in Ornithology no. 2, Cambridge, MA, and Washington, D.C., Nuttall Ornithological Club and American Ornithologists' Union, 279 p.

Meretsky, V.J., Snyder, N.F.R., Beissinger, S.R., Clendenen, D.A., and Wiley, J.W., 2000, Demography of the California condor—Implications for reestablishment: Conservation Biology, v. 14, p. 957–967. [Also available at http://dx.doi.org/10.1046/j.1523-1739.2000.99113.x.]

Miller, A.H., McMillan, I., and McMillan, E., 1965, The current status and welfare of the California condor: National Audubon Society Research Report, no. 6, 61 p.

Ricklefs, R.E., ed., 1978, Report of the advisory panel on the California condor: National Audubon Society Conservation Report, no. 6, 27 p.

Rideout, B.A., Stalis, Ilse, Papendick, Rebecca, Pessier, Allan, Puschner, Birgit, Finkelstein, M.E., Smith, D.R., Johnson, Matthew, Mace, Michael, Stroud, Richard, Brandt, Joseph, Burnett, Joe, Parish, Chris, Petterson, Jim, Witte, Carmel, Stringfield, Cynthia, Orr, Kathy, Zuba, Jeff, Wallace, Mike, and Grantham, Jesse, 2012, Patterns of mortality in free-ranging California condors (*Gymnogyps californianus*): Journal of Wildlife Diseases, v. 48, no. 1, p. 95–112. [Also available at http://dx.doi.org/10.7589/0090-3558-48.1.95.]

Sibley, F.C., 1968, The life history, ecology and management of the California condor (*Gymnogyps californianus*): Laurel, MD, U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Annual Progress Report, Project no. B–22, 34 p.

Snyder, N.F.R., 1983, California condor reproduction, past and present, *in* Temple, S.A., ed., Bird Conservation 1: Madison, WI, University of Wisconsin Press, p. 67–86.

Snyder, N.F.R., 2007, Limiting factors for wild California condors, *in* Mee, Allan, and Hall, L.S., eds., California condors in the 21st century: Series in Ornithology no. 2, Cambridge, MA, and Washington, D.C., Nuttall Ornithological Club and American Ornithologists' Union, p. 9–33.

Snyder, N.F.R., and Hamber, J.A., 1985. Replacement-clutching and annual nesting of California condors: Condor, v. 87, no. 3, p. 374–378. [Also available at https://sora.unm.edu/node/103587.]

Snyder, N.F.R., and Johnson, E.V., 1985, Photographic censusing of the 1982–1983 California condor population: Condor, v. 87, no. 1, p. 1–13.

Snyder, N.F.R., Johnson, E.V., and Clendenen, D.A., 1987, Primary molt of California condors: Condor, v. 89, no. 3, p. 468–485. [Also available at https://sora.unm.edu/node/103834.]

Snyder, N.F.R., and Meretsky, V.J., 2003, California condors and DDE—A re-evaluation: Ibis, v. 145, no. 1, p. 136–151. [Also available at http://dx.doi.org/10.1046/j.1474-919X.2003.00132.x.]

Snyder, N.F.R., and Snyder, H.A., 1989, Biology and conservation of the California condor, *in* Power, D.M., ed., Currrent Ornithology, v. 6: New York, Plenum Press, p. 175–267.

Snyder, Noel, and Snyder, Helen, 2000, The California condor, a saga of natural history and conservation: London, Academic Press, 410 p.

Snyder, N.F.R., and Snyder, H.A., 2005, Introduction to the California condor: Berkeley, CA, University of California Press, 271 p.

Verner, J., 1978, California condors—Status of the recovery effort: Washington, D.C., U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station: Berkeley, CA, General Technical Report PSW–28, 30 p. [Also available at http://www.fs.fed.us/psw/publications/documents/psw_gtr028/psw_gtr028.pdf.]

Walters, J.R., Derrickson, S.R., Fry, D.M., Haig, S.M., Marzluff, J.M., and Wunderle, J.M., Jr., 2010, Status of the California condor (*Gymnogyps californianus*) and efforts to achieve its recovery: Auk, v. 127, no. 4, p. 969–1001. [Also available at http://dx.doi.org/10.1525/auk.2010.127.4.969.]

Wilbur, S.R., 1978, The California condor, 1966–1976—A look at its past and future: North American Fauna, v. 72, p. 1–136. [Also available at http://dx.doi.org/10.3996/nafa.72.0001.]

Wilbur, S.R., 2004, Condor tales—What I learned in twelve years with the big birds: Gresham, OR, Symbios, 400 p.

Endangered Species Research in the Caribbean

James W. Wiley

Although indigenous Amerindian populations adversely affected the biota of their island environments, it was not until the arrival of Europeans that populations of many plant and animal species in the Caribbean Islands declined dramatically (Snyder and others, 1987). Island species are particularly vulnerable to changes in the environment, which, in the extreme, can lead to their extinction. The small populations of many species that occupy islands have limited gene pools and typically show extremes of specialization, characteristics that place those species at high risk for decline and extinction with rapid environmental change. The most important factor in the decline of most Caribbean Island species has been the rapid increase in human population and the environmental changes related to that growth (Snyder and others, 1987).

Among the islands in the Caribbean, Puerto Rico has experienced arguably the most radical transformation of any pre-Columbian habitat. Puerto Rico formerly was covered in natural vegetation, but by 1912 fewer than 1 percent of the original forests were still virgin; all other areas were cut, plowed, grazed, burned, or otherwise degraded (Snyder and others, 1987). The extensive agriculture supported by Puerto Rico's fertile soils allowed the human population on this small (11,489 square kilometers [km^2] [4,436 square miles (mi^2)]—204 kilometers [km] [127 miles (mi)] east to west and 76 km [47 mi] north to south at the widest points) island to increase rapidly, to the point that in 2015, with 4 million residents (about 350/km^2 [900/mi^2]), it was one of the most densely populated islands in the world. Although agriculture is no longer of major importance in Puerto Rico, the human population has continued to grow, causing many plant and animal species to decline or disappear from the island (Snyder and others, 1987).

The endemic Puerto Rican parrot (*Amazona vittata*) is perhaps the most charismatic and emblematic of the species affected by the many environmental problems that have faced Puerto Rican wildlife in the past 500 years. Early accounts reported the parrot's presence throughout the island and on at least three of Puerto Rico's four major satellite islands. All indications are that the parrot was once abundant on the island, perhaps numbering more than 1 million individuals. As Europeans settled the land, parrot populations declined rapidly and disappeared from one after another part of the island (Snyder and others, 1987).

Development of an Endangered Species Research Program in Puerto Rico

In 1946, Ventura Barnés, a biologist with the Commonwealth of Puerto Rico Department of Agriculture and Commerce, expressed concern over the parrot's decline (Rodríguez-Vidal, 1959). From 1953 through 1956, José Rodríguez-Vidal, another Commonwealth biologist, supported by the Pittman-Robertson Program of the U.S. Fish and Wildlife Service (USFWS), conducted the first detailed study of the parrot. Rodríguez-Vidal found that the parrot population in the mid-1950s consisted of only about 200 individuals, and those birds were localized in one small area in eastern Puerto Rico—the Luquillo Forest (Rodríguez-Vidal, 1959). The evidence of the parrot's precariously low numbers and restricted range prompted further apprehension on the part of Commonwealth Department of Agriculture and Commerce biologists,

Puerto Rican parrot ready to fledge, 1975. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

who attempted to reintroduce the parrot in western Puerto Rico, outside its remnant range. Unfortunately, those efforts failed. Early studies by Rodríguez-Vidal and others indicated that a broad array of environmental problems could have been responsible for the parrot's decline (Snyder and others, 1987).

At the urging of Frank Wadsworth, Director of the International Institute of Tropical Forestry (IITF), Río Piedras, Puerto Rico, and with similar efforts by Ray Erickson, assistant director in charge of endangered species research at Patuxent Wildlife Research Center in Laurel, MD (Patuxent), a cooperative program to rescue the parrot was begun in late 1968. The program was developed as a collaboration of the USFWS, U.S. Department of Agriculture, U.S. Forest Service (Forest Service), and the government of the Commonwealth of Puerto Rico, with support from the World Wildlife Fund. The initiation of the Puerto Rican parrot program closely followed passage of the Federal Endangered Species Preservation Act (1966) and inclusion of the parrot on the Federal Endangered Species List in 1967.

At the onset of the Patuxent program in Puerto Rico, all participants recognized that the parrot was in steep decline and extreme measures would probably be needed to save the species. To maximize the likelihood of determining the important factors affecting the parrot population, studies were not restricted to the parrot, but included efforts to understand the biological characteristics of important natural enemies of this species and the biology of other, closely related parrot species (Snyder and others, 1987).

History of Patuxent Biologists at the Puerto Rico Field Station

Cameron Kepler was the first biologist to lead the Caribbean research program. The Forest Service provided Cam and his wife, Angela ("Kay"), with a live-in field station in the heart of the parrot's remnant range in the protected Luquillo Forest, to allow them direct, daily access to the remaining population. The Keplers conducted research on the parrot and other species of conservation concern from 1968 to 1971. Cam Kepler's parrot work focused on determining population size and distribution within the Luquillo Forest, where he developed reliable censusing methods (Kepler, 1972b). Unfortunately, the accuracy of the counts did not show a hoped-for larger population of parrots than had previously been reported. Kepler gave special attention to parrots in the eastern half of the Luquillo Forest, where he documented daily and seasonal foraging behavior and sought to obtain information on recruitment and mortality. Cam left Puerto Rico in late 1971 to become Visiting Researcher at the Edward Grey Institute of Field Ornithology, Oxford University, after which he returned to Patuxent in 1973 to head the whooping crane (*Grus americana*) captive breeding program. He moved on to Hawaii to establish the Maui field station in 1977, but returned to Patuxent (Southeast Research Station, Athens, GA) in 1986 to conduct research on Kirtland's warbler (*Seteophaga kirtlandii*) and other species.

Pico el Yunque, El Yunque National Forest (formerly Luquillo Forest), Puerto Rico, mid-1970s. Photo by Helen Snyder, U.S. Fish and Wildlife Service.

Cam and Kay Kepler, U.S. Fish and Wildlife Service, at field station, Luquillo Forest, Puerto Rico, 1970. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Noel Snyder (left) and John Taapken, U.S. Fish and Wildlife Service, prepare for a day in the field, Puerto Rico, mid-1970s. Photo by Helen Snyder, U.S. Fish and Wildlife Service.

Noel Snyder was the second scientist to head the Puerto Rico field station. Noel and his wife, Helen, conducted detailed studies of parrot biology from 1972 through 1976, concentrating on the population's breeding biology. Constant daylight observations of all known nests (2–5) were conducted from blinds throughout breeding seasons. The Snyders made critical advances in the understanding of the parrot's challenges and, as each bit of knowledge was obtained, immediate efforts were made to correct identified problems. For the first time, the decline of the parrot population was reversed, and the wild population began to increase slowly in number. Further, a captive parrot program was established in Puerto Rico under the watch of the Snyders, who developed fundamental husbandry techniques for captives (Snyder and others, 1987).

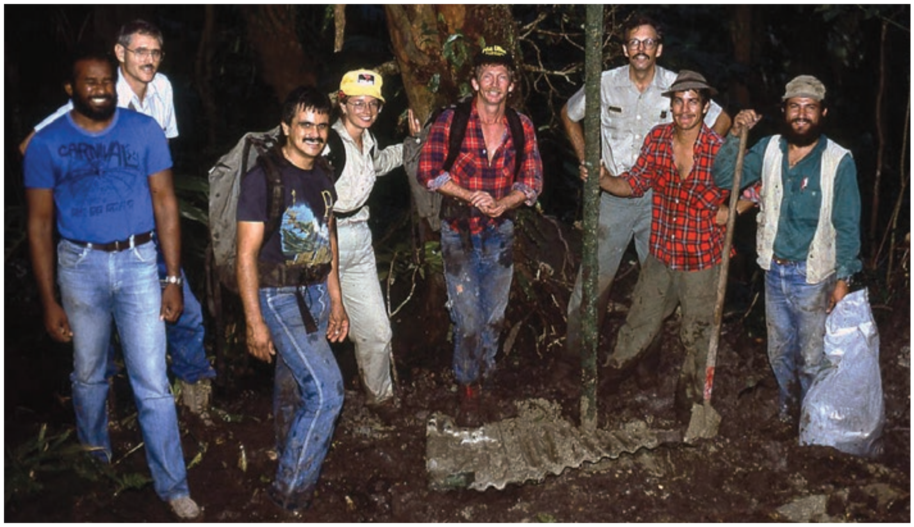
Jim and Beth Wiley's work overlapped with that of the Snyders; they came to the program as Forest Service employees in 1975, replacing Noel when he transferred to Patuxent in 1976. After a writing stint at Patuxent, Noel headed back to the field to study snail kites (*Rostrhamus sociabilis*) in 1978, before leading the California condor (*Gymnogyps californianus*) research program beginning in 1980. Noel left the Patuxent program in 1987, when he retired, but continued writing scientific papers as a private researcher. The Wileys continued the work initiated by the Keplers and Snyders, with emphasis on improving reproductive success in the wild population and developing techniques for releasing captive-produced birds into the wild. The aviary flock increased in number, produced the first captive-bred Puerto Rican parrots, and provided a vital resource for managing the wild flock. During this period, the first releases of captive-produced parrots were made in the Luquillo Forest, and radiotelemetry was used to track post-fledging parrots (Lindsey and Arendt, 1991). The Wileys left Puerto Rico in late 1986, following Noel Snyder to California, where Jim studied the California condor through 1991, when he entered the U.S. Geological Survey (USGS) Cooperative Research Units program.

Gerald Lindsey joined the Puerto Rico program in 1985. After the Wileys' departure, he led the program, conducting additional work on parrot movements by using telemetry. Gerald overlapped with Marcia Wilson, who assumed leadership of the program in 1989, after which time Gerald followed Wiley out to California, where the two worked together again—this time on the condor project—before Gerald transferred to Hawaii in 1991.

Marcia Wilson (1989–91) continued to oversee nesting investigations, the captive program, and tracking of free-flying parrots. In her first year at the station, Marcia was faced with a major hurricane, which damaged much of the Luquillo Forest. Under the challenging post-hurricane conditions, her team documented the greatly reduced population size and distribution of the parrot (Wilson and others, 1994). Marcia left the Puerto Rico field station in 1991 to assume an administrative post at Patuxent in Maryland.

Wylie Barrow (1990–92) and J. Michael ("Joe") Meyers (1990–95) joined Marcia in Puerto Rico as Patuxent staff members before she went to Laurel. Barrow and Meyers continued the telemetry work and developed refined parrot-marking techniques. Meyers was the last of the Patuxent scientists to lead the parrot project, which was abandoned in 1995. Barrow and Meyers continued as USGS wildlife research biologists—Wylie at the National Wetlands Research Center and Joe at Patuxent, stationed at the University of Georgia in Athens.

Even before Marcia Wilson left the Puerto Rico field station, a transition of agency roles had begun. In 1990, the USFWS (Region 4) assumed the lead in management aspects of the parrot conservation program, including operation of the aviary, in cooperation with the Puerto Rico Department of Natural Resources (PRDNR) and the Forest Service. Patuxent



Puerto Rican field crew at East Fork, Puerto Rico, 1989. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

closed the Puerto Rico field station in 1995. Francisco (“Tito”) and Ana Vilella, the first biologists involved in the USFWS program (1989–95), were followed by Augustín Valido (1991–2001), Fernando Nuñez (2000–06), and Tom White (1999–present [2016]), among others.

Challenges and Accomplishments of Patuxent’s Program for Conservation of the Puerto Rican Parrot

At the outset, Patuxent biologists were faced with a staggering, diverse array of environmental problems affecting the parrot (Snyder and others, 1987). Foremost among these was the near-complete, island-wide habitat destruction and alteration. Although parrots formerly were found through all of the island’s habitats ranging from woodland to forest, the species requires habitat that includes trees large enough to harbor cavities for nesting. By the mid-1950s, the Luquillo Forest was the only location in Puerto Rico that supported a parrot population, mainly because it was the only sizable habitat that provided nesting cavities. Early studies by Barnés, Rodríguez-Vidal, and others had provided few clues about the parrot’s problems (Rodríguez-Vidal, 1959). Rodríguez-Vidal and others suggested that poor nest success, apparently due mainly to rat (*Rattus rattus*) and pearly-eyed thrasher (*Margarops fuscatus*) predation, was responsible, but a comprehensive appreciation of nesting and other difficulties was still lacking.

Kepler studied three nests from blinds and determined that many of the birds in the population were not breeding. He also found that the population had declined precipitously since the mid-1950s and, with only about 24 wild birds in existence in 1968, the species was perilously close to extinction in the wild.

Pearly-eyed thrasher—a parrot predator, 1970s. Photo by John Taapken, U.S. Fish and Wildlife Service.

Noel Snyder intensified observations at nests, and initiated comprehensive studies of the ecology of the parrot. Through extensive searches and tree climbing, it was determined that although many large trees and cavities existed within the protection of the Luquillo Forest, only a few existing cavities were actually suitable for parrot nesting. Many of the most amenable cavity-bearing trees had been removed through historic logging and timber-stand improvement practices in the forest. Further, a tradition of felling nest trees or hacking into cavities to harvest chicks for pets selectively destroyed the most suitable (that is, parrot-occupied) nesting habitat. Snyder’s finding that few good cavities were available for nesting parrots led to an effort to improve existing suboptimal cavities as well as provide suitable artificial cavities for parrots.

Detailed studies of parrot breeding biology were initiated in 1973 with constant daylight observations from blinds of as many nests as possible given constraints of personnel and their energy limitations. Those were days of pressing urgency, as the wild population continued its decline toward extinction and the time remaining to find solutions to slow and reverse the rapid loss of birds grew increasingly limited. In fact, when the low point of only 13 birds known in the wild was reached in mid-1975, the goal had to be nothing less than a rapid turnaround in the plummeting population to prevent genetic collapse of the species. This pressure led scientists to conduct intensive trials of innovative methods to protect the parrot and reverse the decline in reproductive output.

Intensive observations revealed the relative unimportance of some natural and exotic predators, including Puerto Rican boa (*Epicrates inornatus*) and introduced Javan mongoose (*Herpestes javanicus*). Although both are known predators of parrots, their role in the decline of the species was evaluated to be less significant than that of other threats. Exotic rats and pearly-eyed thrashers were determined to be important predators and competitors of the parrot. The now-ubiquitous thrasher is evidently a recent invader of the forest and may not have threatened historical populations of parrots. Both thrashers and rats use tree cavities for nesting, with thrashers being particularly aggressive cavity competitors with parrots. Rats were found to be more important as scavengers of abandoned parrot eggs or chicks, but nevertheless remained a threat to nest contents and were controlled within key nesting areas. The thrasher menace was addressed first through direct elimination of birds that demonstrated a threat at parrot nests. That labor-intensive strategy was not sustainable, however, and other control mechanisms were explored. Experimental trials using various alternatives of cavity size and dimension revealed that thrashers and parrots differed with respect to preferred nest-cavity characteristics, thereby indicating a potential option for thrasher management (Snyder and others, 1987). Nest boxes of various configurations and sizes were placed in the forest and their acceptance by thrashers was monitored to determine that species' preferences. Comparing those data with data collected from successful parrot nests revealed that parrots preferred deeper cavities than thrashers. A program of deepening existing parrot nesting cavities was begun, along with provisioning thrashers occupying the parrots' nesting areas with one or more optimal thrasher-sized nest boxes. That strategy greatly reduced thrasher-parrot competition and resulted in improved parrot nest success.

European honeybee (*Apis mellifera*), another exotic species, also proved to be an important cavity competitor with parrots. Honeybees seek cavities with characteristics attractive to parrots. Once established in a parrot nest cavity, honeybees may occupy that site for years, excluding the parrot and further diminishing the overall availability of parrot nest sites. Provisioning of additional nearby artificial boxes was not feasible in controlling honeybee invasions of parrot nests. Fortunately, honeybees typically do not swarm and seek new cavities until after the parrot nesting season. A practice of physically removing honeybee colonies that invaded parrot nests was used successfully for bee control.

Most natural cavities in the Luquillo Forest, where annual rainfall averages 500 centimeters (nearly 200 inches), were found to have wet bottoms, a characteristic that was determined to lower the chances of parrot egg and chick survival. Therefore, in addition to fortifying natural cavities against predators and competitors, all existing cavities were modified to eliminate problems caused by entry of water.

Although capture of parrots, especially taking young from nests, was an important historical factor in the decline of the parrot, that practice had declined by the 1960s, in part because of greater legal protection of the species and its habitat, but also because the pet trade had changed. People who wanted pet parrots were more likely to purchase an exotic parrot from a pet store than to encounter an individual selling Puerto Rican parrots. Unfortunately, this shift from native to exotic birds being sought as pets introduced other threats to the Puerto Rican parrot. Exotic parrots that escaped or were intentionally released from captivity established populations in Puerto Rico, and those species threatened the native species as competitors for habitat. Even though most alien parrots characteristically remained near populated areas, these established exotics posed a far more insidious threat: imported birds might carry exotic diseases against which the native parrot likely would have no defense.

Harvesting of wild parrots was also deterred by program personnel who guarded all active nests throughout the day, while watching for signs of other problems that would affect nest success and productivity. Although manpower constraints did not allow for constant vigil at all nests every day, the number of nests monitored was maximized through the dedication of technicians and volunteers. A tabulation of Patuxent parrot program activities from 1973 to 1979 showed that scientists and assistants had logged more than 20,000 hours of observations from blinds and lookouts.

Radiotelemetry techniques for tracking parrots were developed and have proven invaluable in advancing the conservation of the species. In 1985, studies of parrot movements using telemetry were brought to the forefront of the research program in an effort to determine areas of vulnerability of parrots to predation. Telemetry of marked birds confirmed the conclusions reached from observations and tallies of parrots: post-fledging mortality in the wild flock was high. Known and suspected predators included resident red-tailed hawks (*Buteo jamaicensis*), which are found in extraordinarily high densities in the Luquillo Forest, and wintering peregrine falcons (*Falco peregrinus*) (Lindsey and others, 1994).

As Patuxent scientists tallied the many environmental problems faced by the parrot in the Luquillo Forest, they also examined the possibility of establishing flocks in other parts of Puerto Rico that might exhibit less challenging environmental conditions than those in the extremely wet rain forest at Luquillo and, therefore, might prove to be better suited for

Gerald Lindsey, U.S. Fish and Wildlife Service, tracking parrots with telemetry, Luquillo Forest, Puerto Rico, 1986. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

Helen Snyder, U.S. Fish and Wildlife Service, with Hispaniolan parrots, Sierra de Baharuco, Dominican Republic, 1982. Photo by Noel F.R. Snyder, U.S. Fish and Wildlife Service.

Beth Wiley, U.S. Fish and Wildlife Service, feeding young parrots, Puerto Rican parrot aviary, Luquillo Forest, Puerto Rico, 1980s. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

self-sustaining populations of the parrot. It became obvious that by using current (1985) techniques the parrot population at Luquillo could be sustained only through rigorous and extensive management. Although the Luquillo Forest offered substantial protection against poaching and habitat alteration, the parrot population there was facing more risk factors (especially the wetter environment and denser populations of predators and competitors) than existed in other areas in Puerto Rico. Several areas that might have been appropriate for potential reintroduction areas of the parrot were protected as Commonwealth forests and, with a shift of the island's human population away from an agrarian-based society, natural cover, albeit second growth, had increased dramatically to about 40 percent of land cover. Patuxent scientists believed it would be advantageous to maintain the Luquillo Forest population, which was an important source of behavioral memory, while establishing a second free-flying flock distant from the Luquillo population and supported by an on-site aviary at a second release area. Río Abajo Commonwealth Forest was judged to be a suitable site for this next phase of the recovery effort on the basis of its recent (1940s) history of parrot presence, habitat recovery, security, and lower densities of predators and competitors.

With intensive and extensive efforts by many dedicated people, the Luquillo Forest wild population began a slow recovery from the low of 13 individuals and only 2 breeding pairs in 1975 (Snyder and others, 1987). By 1989, the wild population had reached 47 individuals and as many as 5 (1975, 1984) breeding pairs in a year. In September 1989, however, the first major hurricane in 57 years devastated the Luquillo Forest. Despite an apparent loss of more than half the parrots in the wild, biologists subsequently located a new nesting area that may have been established as a consequence of the storm. In fact, an until-then program-high number of breeding pairs (six) nested in 1991. By 1995, when Patuxent discontinued the parrot program, the wild population had increased to 44 individuals (Snyder and others, 1987).

Captive Puerto Rican parrots were established at Patuxent in 1970, with two birds donated by the Mayagüez Zoo in western Puerto Rico. In early 1972, Paul Sykes (USFWS) and Mike Lennartz (Forest Service) were detailed temporarily to Puerto Rico, where they captured two wild birds despite tremendous odds and physical challenges. One parrot survived and was added to the Patuxent flock. At that time, however, an outbreak of Asiatic Newcastle disease in Puerto Rico led to rigorous quarantine for any birds entering the United States, making it impractical to continue developing the captive flock at Patuxent. The quarantine problem and the need to move parrot eggs and chicks to and from wild nests for protection and treatment led to the establishment of an aviary in the Luquillo Forest in 1973, at which time activities shifted from capture of wild, free-flying birds to harvesting eggs and chicks from the wild to build the captive flock. In fact, most new members of the captive flock were added when eggs or chicks could not be maintained safely in the wild because of potentially lethal threats to their health and safety. At the onset of developing an on-site captive flock, a primary goal was to obtain genetic representation of as many of the existing wild parrots as possible.

With the establishment of the aviary in Puerto Rico, first in the Snyders' living room and later at a dedicated aviary field station building, salvaging and manipulation of wild nest contents became practical. Eggs and chicks threatened by problems such as predation, parasitism by warble (*Philornis pici*) and black soldier (*Hermetia illucens*) flies, or wet cavity floors could be removed temporarily to the aviary, treated or guarded in a safe environment until the threat at the wild nest had been addressed, then returned in time to fledge in the wild (Snyder and others, 1987). The ability to salvage endangered eggs and chicks was further improved through the establishment of an on-site captive flock of the closely related Hispaniolan parrot (*Amazona ventralis*). Captive Hispaniolan parrots served as surrogates for the endangered species in many ways. During periods of high risk at wild Puerto Rican parrot nests, captive-produced Hispaniolan parrot eggs and chicks were fostered into wild nests to replace Puerto Rican parrot eggs and chicks until the danger had passed. Hispaniolan parrots were used as “guinea pigs” to test for suitability of various procedures before they were used on Puerto Rican parrots (Snyder and others, 1987). Furthermore, captive Hispaniolan parrots proved extremely useful and reliable in incubating eggs and brooding of captive- and wild-produced Puerto Rican parrot eggs and chicks. In fact, Hispaniolan parrots were far better at incubating eggs and brooding chicks than were mechanized incubators and brooders, and required far less intense interaction with humans—an important concern for avoiding parrot imprinting on humans and reliance on people as sources of food.

Although the wild population began to recover from its 1975 low, by mid-1979 only 25 or 26 birds were known to exist in the wild. The slow recovery made efforts to use the captive flock to augment the wild population even more important to the parrot’s survival. Efforts to achieve captive reproduction involved developing techniques for sexing the captives and methods of artificial insemination. Experiments in the aviary revealed that replacement clutching was a valuable procedure to increase egg production of parrots; therefore, this practice was incorporated into the captive program to boost production. The first captive-bred Puerto Rican parrot chick was produced in 1979 and was fostered into an active nest, from which it successfully fledged. Thereafter, all fit chicks produced through 1986 were fostered into wild nests.

As part of the preparation for releases of free-flying, captive-produced Puerto Rican parrots, experimental releases of captive-produced Hispaniolan parrots were conducted in the Dominican Republic in 1982. Those releases of 36 birds resulted in an encouraging survival rate of 33 percent, which is approximately the rate the program had been able to achieve through efforts to manage the wild Puerto Rican parrot flock.

Half-grown captive Puerto Rican parrot. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

Mike Lennartz, U.S. Forest Service, carrying Puerto Rican parrots, Luquillo Forest, Puerto Rico, 1980s. Photo by Paul Sykes, U.S. Fish and Wildlife Service.

Additional advancements with radiotelemetry and other marking techniques gave biologists the confidence to release three free-flying, captive-produced Puerto Rican parrots into the Luquillo Forest in 1986. That release was preceded by aversion conditioning of release candidate parrots by using a trained red-tailed hawk. Again, the survival rate was one out of three, and, importantly, the surviving individual reached sexual maturity and bred in the wild.

After Ray Erickson retired from Patuxent in 1980, the program for the conservation of the Puerto Rican parrot was managed differently. Field work was delegated primarily to technicians and junior scientists, and active nests were monitored remotely. Senior scientists devoted more time to communicating with their superiors and writing scientifically defensible research proposals and manuscripts rather than making field observations and guarding nests, a function that had proven critical to the recovery effort (Lindsey, 1992). Therefore, although the junior scientists and technicians were very capable and dedicated to the success of the project, the knowledge, experience, and judgment of the senior scientists were no longer being applied directly to decision-making in the field.

Patuxent administrators continued to work on parrot recovery progress after the USFWS and the PRDNR assumed expanded roles in the parrot program. The second wild population in Río Abajo, Puerto Rico, was not established in spite of strong evidence that the Luquillo Forest environment was not optimal for the survival of a viable, self-sustaining wild population (Snyder and others, 1987, p. 270). Over time, the USFWS strengthened its relations with PRDNR and the program's leadership shifted away from Patuxent. In 1990, the Puerto Rican government established and administered a second captive breeding site at the Río Abajo aviary in western Puerto Rico. Patuxent's parrot program ended in 1995.

Present Status of the Puerto Rican Parrot

The establishment of a disjunct western population of Puerto Rican parrots has been of pivotal importance in the recovery of the parrot. By 2012, the wild population at Río Abajo totaled 40 to 50 birds, after only 6 years of releases. Even more encouraging, 10 pairs in the western area were productive in the wild in 2012. The collective captive populations in the Luquillo Forest and Río Abajo aviaries, which support both of the wild populations, currently (2016) number more than 400 birds. A third wild population was established at a second western site (Maricao) in Puerto Rico in 2015 (U.S. Fish and Wildlife Service, 2016).

Unfortunately, however, after more than 40 years of intense efforts to establish a self-sustaining population of parrots in the Luquillo Forest, the flock still struggles to survive, with a 2016 wild population of only about 12 birds. If other areas of Puerto Rico are included, however, the wild population of the parrot is more than 100 birds (Breining, 2015).

Research on Other Parrot Species and Training of Caribbean Conservationists and Biologists

Comparative studies of the Puerto Rican parrot and parrot species on other islands were an important component of the research conducted by Patuxent biologists. Such studies provided insights into some of the ecological and behavioral aspects of Puerto Rican parrot biology, particularly when "healthy" populations were compared with the small remnant population surviving in Puerto Rico. In such comparisons, wild populations of Hispaniolan parrots were studied where they occurred in large numbers in unaltered ecosystems in the Dominican Republic. Among other species studied, to varying extents, were Bahama parrot (*Amazona leucocephala bahamensis*) in Great Abaco and Great Inagua Islands (Kepler, 1982); Grand Cayman (*A. l. caymanensis*) and Cayman Brac (*A. l. hesterna*) parrots in the Cayman Islands (Wiley, 1991); Cuban parrot (*A. l. leucocephala*) in Cuba and Isla de Pinos (now Isla de la Juventud) (Aguilera and others, 1999); black-billed (*A. agilis*) and yellow-billed (*A. collaria*) parrots in Jamaica; and St. Vincent parrot (*A. guildingii*), St. Lucia parrot (*A. versicolor*), and imperial (*A. imperialis*) and red-necked (*A. arausiaca*) parrots in Dominica (Beissinger and Snyder, 1992; Snyder and others, 1987). In addition to conducting studies of other parrot species and their ecosystems, Patuxent scientists trained many resident conservation officers and biologists on site or during their extended stays at the Puerto Rico field station. Parrot research and management techniques—for example, development of reliable censusing methodology and using artificial and improved natural nest structures to augment natural habitat—were transferred to other islands and incorporated into those countries' parrot conservation efforts.

Other Endangered Species Research by Patuxent Scientists in the Caribbean

Because of the urgency of reversing the population decline of the Puerto Rican parrot, Patuxent biologists focused their research on that species; however, many other Caribbean wildlife species were in need of conservation efforts. For several species, that need could only be speculated upon, because no reliable population numbers or trends were available. Island agencies often asked Patuxent scientists to participate in studies of species in addition to the parrot. Therefore, Patuxent biologists considered it important to explore the biology of other species identified as possibly threatened to provide baseline data on those populations as well as a biologically sound foundation upon which to base local and international conservation efforts.

Seabirds on several of Puerto Rico's offshore islands and cays were the focus of Kepler's extra-parrot research (Kepler, 1978). Cam also conducted the first study of Puerto Rican nightjar (*Caprimulgus noctitherus*), a species that was thought to have become extinct until its rediscovery in 1961. His work and subsequent surveys by other Patuxent biologists produced a basic understanding of the distribution of, status of, and threats to the nightjar. In addition, Cam and Kay Kepler surprised the ornithological world with their discovery of a new species of warbler (the elfin-woods warbler, *Setophaga angelae*) in Puerto Rico in 1970 (Kepler and Parkes, 1972).

Two pigeon species of international concern—plain pigeon (*Patagioenas inornata*) (Wiley and others, 1982) and white-crowned pigeon (*P. leucocephala*) (Wiley and Wiley, 1979)—were studied by Patuxent personnel. Both suffered from the extreme habitat modification seen in Puerto Rico and other Caribbean islands. Results of the studies were used by the PRDNR to manage the pigeon populations. The formerly endangered Puerto Rican plain pigeon (*P. i. wetmorei*) has

Male white-crowned pigeon brooding, Puerto Rico, early 1980s. Photo by Jim Wiley, U.S. Fish and Wildlife Service.

shown remarkable recovery since the 1970s, when only about 120 birds survived, to the several thousand pigeons that are currently (2016) spread over a large portion of Puerto Rico.

The endangered yellow-shouldered blackbird (*Agelaius xanthomus*) and several other native host species of a recently arrived brood parasite, shiny cowbird (*Molothrus bonariensis*), were the subject of extensive research that improved understanding of the ecological relations between the parasite and its hosts (Cruz and others, 1985, 1988; Wiley, 1985, 1988). Patuxent scientists and technicians developed techniques for controlling the effects of brood parasitism on host species, which resulted in improved reproductive success and productivity of hosts, including the yellow-shouldered blackbird (Post and Wiley, 1976, 1977; Wiley and others, 1991).

Several endangered or threatened species of raptors were the subject of in-depth research by Patuxent biologists. The threatened status of endemic races of sharp-shinned (*Accipiter striatus venator*) and broad-winged (*Buteo platypterus brunnescens*) hawks was determined, and Patuxent scientists initiated research on the ecology and behavior of these species. The restricted range of the endemic race of short-eared owl (*Asio flammeus portoricensis*) was determined and its status was identified as being of national concern.

White-necked crow (*Corvus leucognaphalus*), endemic to Hispaniola and Puerto Rico, was extirpated from Puerto Rico in the early 1960s. Patuxent scientists conducted a detailed study to determine the possible cause of that extirpation by studying populations of the crow in the Dominican Republic (Wiley, 2006). That study resulted in a recommendation to reintroduce the crow to Puerto Rico as part of a restoration of the island's original ecosystems and a hedge against extirpation in Hispaniola and, thereby, extinction. The data collected on the crow in the Dominican Republic serve as a baseline for reintroduction into Puerto Rico, although no action to do so has been undertaken.

A detailed study of the critically endangered St. Croix ground lizard (*Ameiva polops*) was conducted by Beth and Jim Wiley at Green and Protestant Cays at the request of the government of the U.S. Virgin Islands. That study provided baseline information on the population size, habitat requirements, and management needs of the lizard. The formerly endangered Puerto Rican boa (*Epicrates inornatus*) was the subject of a diet study by Jim Wiley (2006).

In addition to studies of threatened wildlife species, Patuxent biologists led or were involved in research on several nonthreatened species that were important to the understanding of the ecology of the parrot and other species—for example, investigations of rat populations in the Luquillo Forest, pearly-eyed thrasher ecology and behavior (Snyder and Taapken, 1978), and warble and soldier fly biology.

Patuxent scientists served as members or consultants on Federal recovery teams for the Puerto Rican parrot, Puerto Rican plain pigeon, Puerto Rican nightjar, yellow-shouldered blackbird, and several other species in Puerto Rico and the U.S. Virgin Islands. The Patuxent scientists' research results provided baseline data critical to the development of recovery plans.

Contributions of Patuxent Wildlife Research Center to Caribbean Conservation Efforts

It may never be known whether the efforts of Patuxent scientists and the many other employees and volunteers to save the Puerto Rican parrot actually prevented the species' extinction. Certainly their efforts shifted the parrot's trajectory from a precipitous decline headed for extinction toward population growth, albeit slow growth beset by many setbacks over the years. Although confidence is not yet warranted, the parrot appears to have beaten the odds and recovered from an extremely small population consisting of few individuals and, consequently, a dangerously small gene pool. Of course, whether genetic problems will appear in the future is unknown.

Similarly, it is difficult to evaluate the importance of Patuxent's efforts to save other species from extinction. Certainly Patuxent scientists helped to recognize the problems faced by several species and to provide population estimates upon which the results of future recovery efforts could be assayed. Regardless of the effect of Patuxent on the recovery of individual species, the program had wide and lasting effects on conservation in the region. Importantly, the parrot program was one of the first conservation issues to attract the attention of the Puerto Rican public and helped to establish a foundation for the elevated conservation ethic seen on the island today.

Another of the most important byproducts of the Patuxent research program in the region has been the training of several conservationists and biologists from other islands while the Patuxent scientists were on site or during their extended stays in Puerto Rico. Patuxent scientists visited all islands having parrot populations and involved local conservationists in research and management efforts. Effective and experimental technologies were thereby transferred to other islands and incorporated into those countries' parrot conservation efforts.

The many other people who sacrificed and worked under extremely difficult conditions as they participated in parrot recovery efforts also merit acknowledgment. Most were employed by the Forest Service, USFWS, and PRDNR, but many others generously donated their time as volunteers. Advances made through Patuxent and its collaborating agencies would not have been possible without their valuable contributions. Equally important as the conservation of individual species and their ecosystems are the effects of Patuxent's Caribbean program on the professional development of the many technicians, assistants, graduate students, and volunteers who went on to become influential contributors to conservation efforts in Puerto Rico and elsewhere (table 1). In fact, several of those program associates have become important decision makers in the parrot's recovery.

Table 1. Representative technicians, students, and volunteers who participated in Patuxent Wildlife Research Center's Endangered Species Program in the Caribbean, and highlights of their subsequent careers.

[AM, aviary manager; AT, aviary technician; F&AT, field and aviary technician; FT, field technician; GS, graduate student; T, trainee; US, undergraduate student; V, volunteer; BBS, North American Breeding Bird Survey; EYNF, El Yunque National Forest; GIS, Geographic Information Specialist; IITF, International Institute of Tropical Forestry; NGO, Nongovernment organization; NMEMNRD, New Mexico Energy, Minerals and Natural Resources Department; PRDNR, Puerto Rico Department of Natural Resources; PRP, Puerto Rican parrot; Patuxent, Patuxent Wildlife Research Center; TNWRA, Tennessee Wildlife Resources Agency; UPR, University of Puerto Rico; USDA-APHIS, U.S. Department of Agriculture-Animal and Plant Health Inspection Service; USFS, U.S. Department of Agriculture-Forest Service; USFWS, U.S. Fish and Wildlife Service; USGS, U.S. Geological Survey; USNPS, U.S. National Park Service]

Program participant	Status in program	Post-program contributions
Hernán Abreu	F&AT	Environmental Scientist, USNPS
Wayne Arendt	F&AT/GS	Wildlife Biologist, IITF
Bonnie Bell	F&AT	Enforcement Officer, USFWS
Kelly Brock	AM/GS	Endangered Species Specialist, U.S. Navy
Julio Cardona	V	Scientist and Director, Puerto Rican conservation NGO
Orlando Carrasquillo	F&AT	Supervisory Biological Technican, Ecosystem Team, EYNF, USFS
José Colón	F&AT	Sociedad Ornitología Puertorriqueña, environmental consultant, photographer
Victor Cuevas	F&AT	Visitor Information Service Leader, EYNF, USFS
Carlos Delannoy	F&AT	Professor and Department Chair of Biology, UPR-Mayagüez
Linda DeLay	V	GIS, NMEMNRD
Oscar Díaz-Marrero	F&AT	Refuge Manager, USFWS
Joe diTomaso	F&AT	Department Plant Science Chair and Professor, University of California at Davis
Sharon Dougherty	V/GS	Endangered Species Biologist and cofounder, Circle Mountain Biological Consultants, Inc.
Rosemarie Gnam	V/GS	Chief, Division Science Authority International Affairs Program, USFWS
Nelson Green	T/V	Manager, captive parrot program in Dominica
Quammie Greenaway	T/V	Conservation Officer, Dominica Forestry Department
Robin Knopp	F&AT	Veterinarian
Ed LaRue	F&AT/GS	Endangered Species Biologist and Chief Executive Officer, Circle Mountain Biological Consultants, Inc.
Benjamin ("Benji") Layton	F&AT/GS	Regional Big Game/Waterfowl Coordinator, TNWRA
Sebastian Lousada	V/US	Private aviculturalist
Aurea ("Puchi") Moragón	AT	Website Manager, EYNF, USFS
Fernando Nuñez	F&AT/GS	Leader of PRP Recovery Program, USFWS Region 4
Keith Pardieck	FT	Patuxent BBS Program Coordinator
José Rodríguez	AT	First comanager. of captive program at Río Abajo aviary, PRDNR
Ann Smith	AT	First comanager. of captive program at Río Abajo aviary, PRDNR
Dwight Smith	F&AT	Businessman
John Taapken	F&AT	Businessman and politician
Monica Tomosy	V/GS	Chief, U.S. Bird Banding Laboratory; USFS liaison to USGS
Edgar Vazquez Cabrera	F&AT	Biologist, PRDNR and USDA-APHIS
Michael Zamore	T/V	Wildlife Research officer, Dominica Forestry Department

Selected References

Aguilera, X.G., Alvarez, V.B., Wiley, J.W., and Rosales, J.R., 1999, Population size of Cuban parrots *Amazona leucocephala* and sandhill cranes *Grus canadensis* and community involvement in their conservation in northern Isla de la Juventud, Cuba: Bird Conservation International, v. 9, no. 2, p. 97–112. [Also available at https://doi.org/10.1017/S0959270900002227.]

Beissinger, S.R., and Snyder, N.F.R., 1992, New world parrots in crisis—Solutions from conservation biology: Washington, D.C., Smithsonian Institution Press, 288 p.

Breining, Greg, 2015, Puerto Rican parrot comeback: National Wildlife, accessed June 3, 2016, at https://www.nwf.org/News-and-Magazines/National-Wildlife/Birds/Archives/2015/Puerto-Rican-Parrot-Comeback.aspx.

Brock, M.K., and White, B.N., 1991, Multifragment alleles in DNA fingerprints of the parrot, *Amazona ventralis*: Journal of Heredity, v. 82, no. 3, p. 209–212. [Also available at http://jhered.oxfordjournals.org/cgi/content/abstract/82/3/209.]

Cruz, Alexander, Manolis, T., and Wiley, J.W., 1985, The shiny cowbird in the Caribbean: Ecology of an avian brood parasite undergoing range expansion, *in* Buckley, P.A., Foster, M.S., Morton, E.S., Ridgely, R.S., and Buckley, F.G., eds., Neotropical ornithology: Ornithological Monographs no. 36, p. 607–620. [Also available at http://www.jstor.org/stable/40168308.]

Cruz, Alexander, and Wiley, J.W., 1989, The decline of an adaptation in the absence of a presumed selection pressure: Evolution, v. 43, no. 1, p. 55–62. [Also available at http://dx.doi.org/10.2307/2409163.]

Cruz, Alexander, Wiley, J.W., Nakamura, T.K., and Post, W., 1988, The shiny cowbird, *Molothrus bonariensis,* in the West Indian region—Biogeographical and ecological implications, *in* Woods, C.A., ed., Biogeography of the West Indies—Past, present, and future: Gainesville, FL, Sandhill Crane Press, Inc., p. 519–540.

Derrickson, S.R., and Snyder, N.F.R., 1992, Potentials and limits of captive breeding in parrot conservation, *in* Beissinger, S.R., and Snyder, N.F.R., eds., New World parrots in crisis—Solutions from conservation biology: Washington, D.C., Smithsonian Institution Press, p. 133–163.

Enkerlin-Hoeflich, E.C., Snyder, N.F.R., and Wiley, J.W., 2006, Behavior of wild *Amazona* and *Rhynchopsitta* parrots, with comparative insights from other psittacines, *in* Luescher, A.U., ed., Manual of parrot behavior: Ames, IA, Blackwell Publishing, p. 13–25.

Kepler, A.K., 1977, Comparative study of todies (Todidae)—With emphasis on the Puerto Rican tody, *Todus mexicanus*: Publications of the Nuttall Ornithological Club, no. 16, 190 p.

Kepler, C.B., 1972a, Notes on the ecology of Puerto Rican swifts, including the first record of the white-collared swift *Streptoprocne zonaris*: Ibis, v. 114, no. 4, p. 541–543. [Also available at http://dx.doi.org/10.1111/j.1474-919X.1972.tb00856.x.]

Kepler, C.B., 1972b, The ecology of the Puerto Rican parrot, an endangered species: Ibis, v. 114, no. 3, p. 442–443. [Also available at http://dx.doi.org/10.1111/j.1474-919X.1972.tb00846.x.]

Kepler, C.B., 1978, The breeding ecology of sea birds on Monito Island, Puerto Rico: Condor, v. 80, no. 1, p. 72–87. [Also available at http://sora.unm.edu/node/102818.]

Kepler, C.B., and Kepler, A.K., 1973, The distribution and ecology of the Puerto Rican whip-poor-will, an endangered species: Living Bird, v. 11, p. 207–239.

Kepler, C.B., and Kepler, A.K., 1978, The sea-birds of Culebra and its adjacent islands, Puerto Rico: Living Bird, v. 16, p. 21–50.

Kepler, C.B., and Parkes, K.C., 1972, A new species of warbler (Parulidae) from Puerto Rico: Auk, v. 89, no. 1, p. 1–18. [Also available at http://sora.unm.edu/node/22201.]

Lindsey, G.D., 1992, Nest guarding from observation blinds: Strategy for improving Puerto Rican parrot nest success: Journal of Field Ornithology, v. 63, no. 4, p. 466–472. [Also available at http://www.jstor.org/stable/4513745.]

Lindsey, G.D., and Arendt, W.J., 1991, Radio tracking Puerto Rican parrots—Assessing triangulation accuracy in an insular rain forest: Caribbean Journal of Science, v. 27, nos. 1–2, p. 46–53.

Lindsey, G.D., Arendt, W.J., and Kalina, Jan, 1994, Survival and causes of mortality in juvenile Puerto Rican parrots: Journal of Field Ornithology, v. 65, no. 1, p. 76–82. [Also available at https://sora.unm.edu/node/51865.]

Lindsey, G.D., Arendt, W.J., Kalina, Jan, and Pendleton, G.W., 1991, Home range and movements of juvenile Puerto Rican parrots: Journal of Wildlife Management, v. 55, no. 2, p. 318–322. [Also available at http://dx.doi.org/10.2307/3809157.]

Meyers, J.M., 1994, Leg bands cause injuries to parakeets and parrots: North American Bird Bander, v. 19, no. 4, p. 133–136. [Also available at https://sora.unm.edu/node/93291.]

Meyers, J.M., 1995, A colored leg banding technique for *Amazona* parrots: Journal of Field Ornithology, v. 66, no. 4, p. 582–589. [Also available at https://sora.unm.edu/node/52018.]

Meyers, J.M., 1995, Puerto Rican parrots, *in* LaRoe, E.T., Farris, G.S., Puckett, C.E., Doran, P.D., and Mac, M.J., eds., Our living resources—A report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems: Washington, D.C., U.S. Department of the Interior, National Biological Service, p. 83–85. [Also available at https://pubs.er.usgs.gov/publication/70148108.]

Meyers, J.M., 1996, Evaluation of 3 radio transmitters and collar designs for *Amazona*: Wildlife Society Bulletin, v. 24, no. 1, p. 15–20. [Also available at http://www.jstor.org/stable/3782826.]

Meyers, J.M., 1996, New nesting area of Puerto Rican parrots: Wilson Bulletin, v. 108, no. 1, p. 164–166. [Also available at http://sora.unm.edu/node/131371.]

Meyers, J.M., Arendt, W.J., and Lindsey, G.D., 1996, Survival of radio-collared nestling Puerto Rican parrots: Wilson Bulletin, v. 108, no. 1, p. 159–163. [Also available at http://sora.unm.edu/node/131370.]

Post, William, and Wiley, J.W., 1976, The yellow-shouldered blackbird—Present and future: American Birds, v. 30, no. 1, p. 13–20. [Also available at https://sora.unm.edu/node/112547.]

Post, William, and Wiley, J.W., 1977, Reproductive interactions of the shiny cowbird and the yellow-shouldered blackbird: Condor, v. 79, p. 176–184. [Also available at https://sora.unm.edu/node/102731.]

Post, William, and Wiley, J.W., 1977, The shiny cowbird in the West Indies: Condor, v. 79, p. 119–121. [Also available at https://sora.unm.edu/node/102712.]

Rodríguez-Vidal, J.A., 1959, Puerto Rican parrot study: San Juan, Puerto Rico, Department of Agriculture of the Commonwealth of Puerto Rico, Monograph no. 1, 15 p.

Snyder, N.F.R., 1977, Puerto Rican parrots and nest-site scarcity, *in* Temple, S.A., ed., Endangered birds—Management techniques for preserving threatened species: Madison, WI, University of Wisconsin Press, p. 47–53.

Snyder, N.F.R., 1978, Increasing reproductive effort and success by reducing nest-site limitations—A review, *in* Temple, S.A., ed., Endangered birds—Management techniques for preserving threatened species: Madison, WI, University of Wisconsin Press, p. 27–33.

Snyder, N.F.R., Derrickson, S.R., Beissinger, S.R., Wiley, J.W., Smith, T.B., Toone, W.D., and Miller, B., 1996, Limitations of captive breeding in endangered species recovery: Conservation Biology, v. 10, no. 2, p. 338–348. [Also available at http://www.jstor.org/stable/2386850.]

Snyder, N.F.R., King, W.B., and Kepler, C.B., 1982, Biology and conservation of the Bahama parrot: Living Bird, v. 19, p. 91–114.

Snyder, N.F.R., and Taapken, J.D., 1978, Puerto Rican parrots and nest predation by pearly-eyed thrashers, *in* Temple, S.A., ed., Endangered birds—Management techniques for preserving threatened species: Madison, WI, University of Wisconsin Press, p. 113–120.

Snyder, N.F.R., and Wiley, J.W., 1994, Puerto Rican parrot conservation—A retrospective evaluation by two former leaders of the program (1972–1986): PsittaScene, v. 6, no. 1, p. 6–7. [Also available at https://www.parrots.org/files/psitta/442/ps_6_1_feb_94.pdf.]

Snyder, N.F.R., Wiley, J.W., and Kepler, C.B., 1987, The parrots of Luquillo—Natural history and conservation of the Puerto Rican parrot: Los Angeles, CA, Western Foundation of Vertebrate Zoology, 384 p.

U.S. Fish and Wildlife Service, 2016, Conserving the nature of America--Significant achievement in the transfer of Puerto Rican parrots to the Maricao Commonwealth Forest: accessed November 10, 2016, at https://www.fws.gov/news/ShowNews.cfm?ID=26D2B5A7-5056-AF00-5BA3BAAD09E24C98.

Wiley, J.W., 1979, The white-crowned pigeon in Puerto Rico: Status, distribution, and movements: Journal of Wildlife Management, v. 43, no. 2, p. 402–413. [Also available at http://dx.doi.org/10.2307/3800349.]

Wiley, J.W., 1980, The Puerto Rican parrot (*Amazona vittata*)—Its decline and the program for its conservation, *in* Pasquier, R.F., ed., Conservation of New World parrots: Washington, D.C., Smithsonian Institution Press for the International Council for Bird Preservation, Technical Publication no. 1, p. 133–159.

Wiley, J.W., 1983, The role of captive propagation in Puerto Rican parrot conservation, *in* Risser, A., and Todd, F., eds., Jean Delacour/International Federation for the Conservation of Birds—Symposium on breeding birds in captivity: Los Angeles, CA, International Federation for the Conservation of Birds, p. 441–453.

Wiley, J.W., 1985a, Bird conservation in the United States Caribbean, *in* Temple, S.A., ed., Bird conservation 2: Madison, WI, University of Wisconsin Press for International Council for Bird Preservation, p. 107–159.

Wiley, J.W., 1985b, Shiny cowbird parasitism in two avian communities in Puerto Rico: Condor, v. 87, no. 2, p. 165–176. [Also available at http://sora.unm.edu/node/103553.]

Wiley, J.W., 1985c, Status and conservation of forest raptors in the West Indies, *in* Newon, I., and Chancellor, R., eds., Raptor conservation: International Council for Bird Preservation, Technical Publication no. 5, p. 199–204.

Wiley, J.W., 1985d, The captive programme for the endangered Puerto Rican parrot *Amazona vittata*: Aviculture Magazine, v. 91, no. 2, p. 110–116.

Wiley, J.W., 1985e, The Puerto Rican parrot and competition for its nest sites, *in* Moors, P.J., ed., Conservation of island birds—Case studies for the management of threatened island species: Cambridge, England, International Council for Bird Preservation, Technical Publication no. 3, p. 213–223.

Wiley, J.W., 1986a, Habitat change and its effects on Puerto Rican raptors: International Council for Bird Preservation Birds of Prey Bulletin no. 3, p. 51–56. [Also available at http://www.raptors-international.org/book/birds_of_prey_1986/Wiley_1986_51-56.pdf.]

Wiley, J.W., 1986b, Status and conservation of raptors in the West Indies: International Council for Bird Preservation Birds of Prey Bulletin no. 3, p. 57–70. [Also available at http://www.raptors-international.org/book/birds_of_prey_1986/Wiley_1986_57-70.pdf.]

Wiley, J.W., 1988, Host selection by the shiny cowbird: Condor, v. 90, no. 2, p. 289–303. [Also available at http://sora.unm.edu/node/103956.]

Wiley, J.W., 1991, Status and conservation of parrots and parakeets in the Greater Antilles, Bahama Islands, and Cayman Islands: Bird Conservation International, v. 1, p. 187–214. [Also available at https://doi.org/10.1017/S0959270900000599.]

Wiley, J.W., 1996, Ornithology in Puerto Rico and the Virgin Islands, *in* Figueroa Colón, J.C., ed., The scientific survey of Puerto Rico and the Virgin Islands—An eighty-year reassessment of the islands' natural history: New York, Annals of the New York Academy of Sciences, v. 776, p. 149–179. [Also available at http://dx.doi.org/10.1111/j.1749-6632.1996.tb17419.x.]

Wiley, J.W., 2003, Habitat association, size, stomach contents, and reproductive condition of Puerto Rican boa (*Epicrates inornatus*): Caribbean Journal of Science, v. 39, no. 1, p. 189–194.

Wiley, J.W., 2006, The ecology, behavior, and conservation of a West Indian corvid, the white-necked crow (*Corvus leucognaphalus*): Ornithología Neotropical, v. 17, no. 2, p. 105–146. [Also available at https://sora.unm.edu/node/119745.]

Wiley, J.W., Cotte, R., Parker, W.T., Raffaele, H.A., Vivaldi, J.L., and Snyder, N.F.R., 1982, Puerto Rican plain pigeon recovery plan: Atlanta, GA, U.S. Fish and Wildlife Service, 52 p. [Also available at https://www.fws.gov/caribbean/PDF/Recovery_Plans/Columba_inornata_wetmorei.pdf.]

Wiley, J.W., and Gee, G., 1981, Using captive propagation to help save the Puerto Rican parrot: AFA Watchbird, v. 8, no. 5, p. 4–11. [Also available at https://journals.tdl.org/watchbird/index.php/watchbird/article/view/2037/0.]

Wiley, J.W., Gnam, R.S., Koenig, S.E., Dornelly, A., Gálvez, X., Bradley, P.E., White, T., Zamore, M., Reillo, P.R., and Anthony, D., 2004, Status and conservation of the family *Psittacidae* in the West Indies: Caribbean Journal of Ornithology, v. 17, p. 94–154.

Wiley, J.W., and Perry, H.R., Jr., 1985, El programa de investigaciones ornitológicas de Patuxent, *in* Stiles, F.G., and Aguilar, P.G., eds., Proceedings I Symposio de Ornitologia Neotropical, IX Congreso LatinAmericano de Zoologico, 14–15 Octobre 1983: Arequipa, Peru, Asociación Peruana para Conservación de la Naturaleza, World Wildlife Fund–U.S. and U.S. Fish and Wildlife Service, 126 p.

Wiley, J.W., Post, William, and Cruz, Alexander, 1991, Conservation of the yellow-shouldered blackbird *Agelaius xanthomus*, an endangered West Indian species: Biological Conservation, v. 55, no. 2, p. 119–138. [Also available at http://dx.doi.org/10.1016/0006-3207(91)90052-B.]

Wiley, J.W., Snyder, N.F.R., and Gnam, R.S., 1992, Reintroduction as a conservation strategy for parrots, *in* Beissinger, S.R., and Snyder, N.F.R., eds., New World parrots in crisis—Solutions from conservation biology: Washington, D.C., Smithsonian Institution Press, p. 165–200.

Wiley, J.W., and Wiley, B.N., 1979, The biology of the white-crowned pigeon: Wildlife Monograph no. 64, 54 p.

Wiley, J.W., and Wunderle, J.M., Jr., 1993, The effects of hurricanes on birds, with special reference to Caribbean islands: Bird Conservation International, v. 3, no. 4, p. 319–349. [Also available at http://dx.doi.org/10.1017/S0959270900002598.]

Wilson, K.A., Field, R., and Wilson, M.H., 1995, Successful nesting behavior of Puerto Rican parrots: Wilson Bulletin, v. 107, no. 3, p. 518–529. [Also available at http://sora.unm.edu/node/131313.]

Wilson, K.A., Wilson, M.H., and Field, Rebecca, 1997, Behavior of Puerto Rican parrots during failed nesting attempts: Wilson Bulletin, v. 109, no. 3, p. 490–503. [Also available at http://sora.unm.edu/node/131502.]

Wilson, M.H., Kepler, C.B., Snyder, N.F.R., Derrickson, S.R., Dein, F.J., Wiley, J.W., Wunderle, J.M., Jr., Lugo, A.E., Graham, D.L., and Toone, W.D., 1994, Puerto Rican parrots and potential limitations of the metapopulation approach to species conservation: Conservation Biology, v. 8, no. 1, p. 114–123. [Also available at http://dx.doi.org/10.1046/j.1523-1739.1994.08010114.x.]

Wunderle, J.M., Jr., Snyder, N.F.R., Muiznieks, Britta, Wiley, J.W., and Meyers, J.M., 2003, Histories of Puerto Rican parrot nests in the Caribbean National Forest/Luquillo Experimental Forest, 1973–2000: Portland, OR, U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, General Technical Report IITF–GTR–21, 28 p. [Also available at http://www.fs.fed.us/pnw/pubs/iitf/gtr21.pdf.]

A Personal Perspective on Searching for the Ivory-Billed Woodpecker: A 41-Year Quest

Paul W. Sykes, Jr.

Introduction

I first learned about the Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, while attending high school in the mid-1950s. Patuxent wildlife biologists Brooke Meanley, Chandler (Chan) S. Robbins, and Robert (Bob) E. Stewart, Sr., visited me at my parents' home in Norfolk, VA. I was the compiler of the Norfolk County Christmas Bird Count (which included the eastern portion of the Virginia sector of the Dismal Swamp). As part of that count, we had for several years been estimating populations of red-winged blackbirds (*Agelaius phoeniceus*) and common grackles (*Quiscalus quiscula*) in the millions. Patuxent was beginning studies of blackbird depredations on agricultural crops.

Approximately 10 years later, while I was attending graduate school at North Carolina State University at Raleigh, the chairman of my graduate committee, Thomas L. Quay, professor of zoology, suggested that I visit Patuxent to meet some of the staff and investigate job opportunities with the Bureau of Sport Fisheries and Wildlife (which became the U.S. Fish and Wildlife Service) within the U.S. Department of the Interior. I made two such trips, and was greatly impressed by the caliber of the research being conducted at Patuxent.

Toward the end of my graduate studies during the first half of 1967, I applied for a position as a wildlife biologist (research) at Patuxent, and, much to my delight, I got the job. I was hired on July 7, 1967, by Ray C. Erickson, Assistant Director of Patuxent; he was also in charge of the Endangered Wildlife Research Program housed at Snowden Hall on the Patuxent campus. At that time, Eugene (Dusty) H. Dustman was the center director, Pearle Sisler was head of the personnel office, and Bertha Preston was the program's secretary, with Barbara Nichols coming on board several years later. Others in the program at the time included Glen Smart, Gene Cowan, Bruce Williams, James Stephenson, and Wayne Shifflett. Wildlife biologists at the field stations included John L. Sincock at Kauai, Winston (Win) E. Banko on the "Big Island" of Hawaii, Fred C. Sibley in California, Roy E. Tomlinson in Arizona, and Donald Fortenbery in South Dakota. Bill and Lucille Stickel and Brooke Meanley and family lived nearby at Patuxent in a two-story duplex. (In the late 1960s, fellow employees were addressed by their first names, from the Bureau director down. The agency was like extended family.)

After the departure of Norman Holgerson, my duty station was a one-man office in Delray Beach, Palm Beach County, FL. This was my first permanent job, and resulted in a career that lasted just short of 40 years; I retired on April 3, 2007. My primary duties were to investigate the distribution, population dynamics, and biology of the snail kite (*Rostrhamus sociabilis plumbeus*) (at that time the common name was Everglade kite or Florida Everglade kite), the ivory-billed woodpecker (*Campephilus principalis principalis*), the dusky seaside sparrow (*Ammodramus maritimus nigrescens*) (formerly considered a full species, unfortunately now extinct), and other endangered species in the southeastern United States.

The Bureau of Sport Fisheries and Wildlife Research project work unit on the ivory-billed woodpecker (IBWO), "Status and distribution of the American ivory-billed

Nestling ivory-billed woodpecker and J.J. Kuhn, local guide, in the Singer Tract, LA, March 6, 1938. Photo by James T. Tanner, graduate student, Cornell University. Photo coutesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

woodpecker," authorized me to work with the species in the southeastern United States from October 1, 1967, to October 1, 1970. Given the circumstances, this project became open-ended, or, as fellow researcher J. Michael Scott (at the Hawaii field station on the "Big Island") told Ray Erickson at one of our Endangered Species Research Program meetings at Patuxent, "Thanks for the long leash."

The information presented here is derived from my weekly and monthly activity reports (1967–92), memoranda and other correspondence, office files, my field notes, the literature, and consultations and work with others. My efforts to find the IBWO are described here for the first time, and are presented in chronological order. The names of those who contributed to my field work are included for the historical record. Without the help of these persons and many others, my searches would not have been possible.

J.J. Kuhn, a local guide, and Peter Paul Kellogg, Cornell University, making sound recording of ivory-billed woodpecker in the Singer Tract, LA, April 1935. Photo by James T. Tanner, Cornell University graduate student. Photo courtesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

Searches

On my first attempt to locate an IBWO, I traveled alone to the Green Swamp in northern Polk County, FL, on October 14, 1967. On October 16, I accompanied Richard A. Long (wildlife officer, Florida Game and Fresh Water Fish Commission—now the Florida Fish and Wildlife Commission), in an open 4x4 Jeep into the Green Swamp along the Withlacoochee River in Polk and Sumter Counties. It was on this trip that I heard what sounded like a loud white-breasted nuthatch (*Sitta carolinensis*)—like the "kent" calls of an IBWO. I had on tape a copy of IBWO vocalizations from the Cornell Lab of Ornithology (Ithaca, NY) that Professors Arthur A. Allen and Peter Paul Kellogg and doctoral student James T. Tanner had recorded at the Singer Tract (an 81,000-acre property named after the sewing machine company that owned the land) in northeastern Louisiana in the mid-1930s. I had studied this tape prior to beginning my search so I could readily recognize the vocalizations if I encountered any IBWOs.

When I heard the nuthatch-like vocalizations, the hair on the back of my neck stood up and I experienced an intense adrenaline rush. Richard quickly stopped the vehicle on the bank of the river. I stepped out of the vehicle and looked around. The sound originated at the top of a water oak (*Quercus nigra*)—it was a blue jay (*Cyanocitta cristata*)! I was both surprised and disappointed—but I learned that blue jays can produce a very good imitation of an IBWO call and, therefore, hearing the bird without seeing it can lead to false reports of this woodpecker. From that time to the present (2016), I have heard from observers who witnessed blue jays making such calls; one report was from New Jersey, far from the IBWO's historic range. Other species, particularly northern flickers (*Colaptes auratus*), also may on occasion mimic an IBWO call. Henry M. Stevenson (professor of zoology, Florida State University, oral commun., about 1969) told me he had witnessed a flicker giving a call that sounded like that of an IBWO in either Alabama or northern Florida (I cannot recall which). In Louisiana, graduate student Laurence (Laurie) C. Binford (Louisiana State University, oral commun., about 1969) heard a flicker giving a call that sounded like an IBWO. In both cases, the source of the calls was found and the birds' true identities were determined. At the time, neither of these gentlemen knew of the other's observation.

H.V. (Tommy) Hines (pilot and game management agent, Bureau of Sport Fisheries and Wildlife) flew me over the Green Swamp and along the course of the Withlacoochee River on October 17, 1967. No IBWOs were found in the swamp on October 14, 16, or 17.

I conducted a search in southwestern Florida on October 31, 1967, with James (Jimmy) Poncier (wildlife officer, Florida Game and Fresh Water Fish Commission). We worked Bright Hour Ranch, Sour Orange Hammock, Myrtle Slough, and Prairie Creek in DeSoto County, and the Sparkman area and Babcock Ranch in Charlotte County. In the late afternoon, I flew with John R. Dowd (pilot, Florida Game and Fresh Water Fish Commission) for 1.5 hours at low altitude (300–400 feet [ft]), making a big loop over the State psychiatric hospital on Florida State Road 70, Sour Orange Hammock, Tipper Bay Slough, Telegraph Swamp, Babcock Ranch, Prairie Creek, and Tiger Bay Slough. No IBWOs were detected and no sign of their presence was noted.

On November 10, 1967, Henry Stevenson (Florida State University) and I searched for IBWOs on the Chipola River and at Dead Lake in Gulf and Calhoun Counties in the Florida Panhandle. We lost our way on the river for a short time, as we returned to the boat landing after dark with no flashlight or other light source. We did not observe any IBWOs or see any sign of their presence. In 1950, IBWOs were reported in this area by ornithologists Whitney Eastman and Muriel Kelso, and also by Davis Crompton, a birder from Massachusetts, but in that same year James T. Tanner (then professor of zoology, University of Tennessee) and Herbert L. Stoddard, Sr. (director and president of Tall Timbers Research Station, Tallahassee, FL), searching separately, did not locate the species. However, naturalist John V. Dennis reported hearing an IBWO call five times in the Chipola River Swamp on April 5, 1951. This appears to be the last report of the IBWO in the area (Jackson, 2004).

On November 12, 1967, Wayne Shifflett (then a refuge management trainee at St. Marks National Wildlife Refuge, formerly at Patuxent) and I looked for IBWOs along the east side of the Apalachicola River, in Tates Hell Swamp, and in part of the Apalachicola National Forest in Franklin County, FL, with negative results. I spent much of November 13 on the east side of the Apalachicola River in Liberty County, also with negative results.

I visited Tall Timbers Research Station just north of Tallahassee on November 14, 1967, where W. Wilson Baker (biologist at the station) introduced me to Herbert Stoddard. Stoddard stated that he had seen IBWOs several times, but did not divulge dates, locations, or other details of his sightings (Herbert Stoddard, Tall Timbers Research Station, oral commun., 1967). I learned later that most of Stoddard's sightings had occurred years earlier when he was much younger. Presumably such sightings were in the Panhandle of Florida. I never discovered the exact locations of most of them.

James Tanner near large sweet gum tree in optimum ivory-billed woodpecker habitat, Singer Tract, LA, May 1937. Photo by James T. Tanner, Cornell University graduate student. Photo courtesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

My first special assignment away from Patuxent's Florida field station was to verify reports by John Dennis of IBWO sightings in what is now the Big Thicket National Preserve of eastern Texas. I had first met John in the late 1950s on Martha's Vineyard, MA, when I was an undergraduate student. At that time he was mist-netting (capturing birds with Japanese mist nets) and banding landbird migrants as part of "Operation Recovery," a cooperative study of fall bird migration in the eastern United States, mainly along the Atlantic Coast. On April 17, 1948, John Dennis and Davis Crompton had rediscovered and photographed IBWOs in eastern Cuba after the species had not been seen for several years (Dennis, 1948; Jackson, 2004). In 1966–68, John was under contract with the Bureau of Sport Fisheries and Wildlife to locate IBWOs that were being reported by local residents in eastern Texas.

I met Harry Goodwin (Endangered Species Manager, U.S. Fish and Wildlife Service [USFWS]) at his office in the Main Interior Building in Washington, D.C., on August 9, 1967. Harry briefed me on the reports that John Dennis had been sending him of IBWO sightings, vocalizations, feeding signs, etc., in East Texas. Harry needed to know for certain if these reports were accurate (at one point Dennis estimated 5 to 10 pairs). The information Harry presented to me was very encouraging.

On the afternoon of August 25, 1967, I was at an IBWO meeting at Patuxent that was attended by John Dennis, Ray Erickson, and Harry Goodwin, and also Patuxent research managers Ralph Andrews and Gene Knoder. At this gathering, I obtained more information on contacts and places to search in East Texas, coastal South Carolina, Georgia, and Florida. In the course of our discussions, Dennis mentioned that because beetle infestations in large timber stands might tend to attract any IBWO present in an area, it might be worthwhile to contact foresters in the southeastern United States for possible leads to the locations of such infestations (John Dennis, contractor, U.S. Fish and Wildlife Service, oral commun., 1967). At the close of the meeting, he gave me several suggestions based on his long experience searching for IBWOs that I found helpful during field work in Texas starting in early January 1968.

With the information I had been given at this meeting and the earlier meeting with Harry Goodwin, I fully expected to find an IBWO in the southeastern United States in the coming year. In preparation for the trip to Texas, I invited James Tanner to join me in searching for IBWO in Texas, and he accepted. Jim (who died in January 1991) was the world's foremost authority on the IBWO and is the only person ever to have conducted a formal study of the species in the wild in the United States (Tanner, 1942), as part of his doctoral program at Cornell University under the direction of Arthur Allen. All other investigators, from Mark Catesby in 1731 to recent times (Catesby, 1731; Jackson, 2002), have had only brief encounters with IBWOs.

Male ivory-billed woodpecker at nest in red maple tree, Singer Tract, LA, April 1935. Photo by James T. Tanner, Cornell University graduate student. Photo coutesy of Tensas River National Wildlife Refuge Collection at the Louisiana State University Library, Baton Rouge, LA.

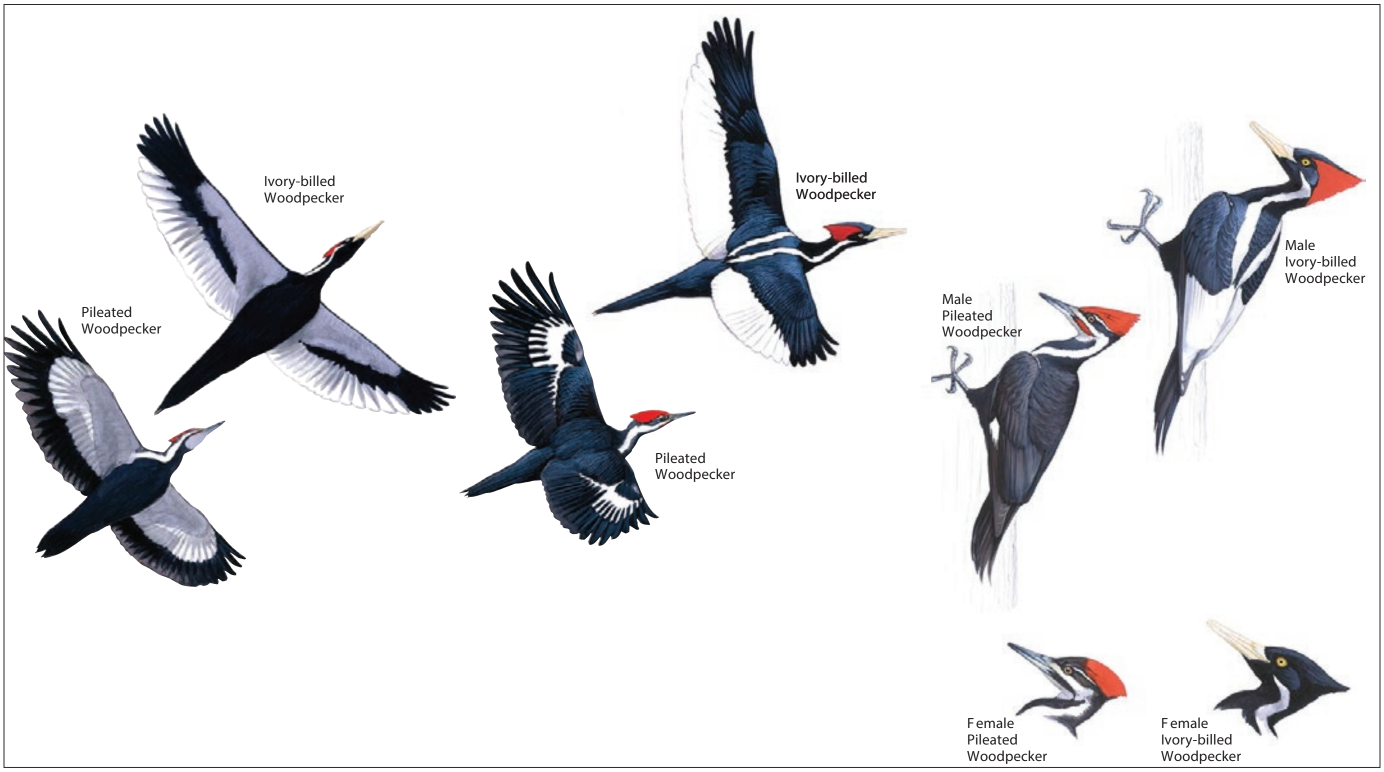
While en route to East Texas in early January 1968, I visited Henry Stevenson at Florida State University; George H. Lowery, Jr., and Robert J. Newman (professors of zoology, Museum of Zoology, Louisiana State University, Baton Rouge); and Jacob (Jake) M. Valentine (Gulf Coast Wildlife Management Biologist, Bureau of Sport Fisheries and Wildlife, Lafayette, LA) to discuss IBWOs and Mississippi sandhill cranes (*Grus canadensis pulla*). Upon reaching Texas, I talked with Bureau and State personnel about the IBWO and made arrangements to obtain access to boats and to fly over the Neches River flood plain. I began field work on January 10 and continued through January 31, 1968, in the Neches and Angelina River bottoms and a section along the Trinity River to the west, spending a total of 118 hours in the field. During the search, I covered 64 mi on foot, 372 mi by boat, 380 mi by airplane, and 2,600 mi in vehicles. Jim Tanner and I searched in the field together from January 19 to 27, and the two of us spent January 23 in the field with John Dennis. During January 21–27, Jim Tanner and I were joined in the field by Ernest McDaniel. Ernest was a teacher living in Kountze, TX, and a past president of the Texas Ornithological Society. He is an accomplished birder and woodsman, and knows East Texas well, particularly the area north of Dam B Reservoir on the Neches River bottoms, where most reported sightings have occurred. Ernest had been searching in the Big Thicket region for the past 6 years, but had not seen or heard an IBWO. During 1966 and 1967, he increased his efforts to find the bird. He had been checking woodpecker cavities, finding only evidence of the common species of woodpeckers and small mammals. (It should be noted that he could free-climb a tree like a squirrel.)

The Neches River bottoms are used heavily for outdoor recreation and commercial purposes. We interviewed several people who had reported seeing an IBWO. We searched carefully (two or more times) on foot in localities where the birds had been reported, as well as at other areas that appeared promising. Stopping and listening for a period of several minutes at intervals was standard procedure in all field work. The search protocol also included looking for feeding signs (bark scaling, pits, etc.) and possible nesting/roosting cavities. Tanner (1942) used this technique for locating IBWOs and found it to be highly successful.

I did not see or hear any IBWOs or find any tangible evidence to confirm their presence in eastern Texas. Reliable observers have not seen IBWOs despite being alert and searching for them in the Neches River Basin. We found during searching that feeding sign and several roost holes believed to be made by IBWOs were actually those of the pileated woodpecker (*Dryocopus pileatus*), a very common species in the Big Thicket region.

With most IBWO reports, a bird had either been seen but not heard, or heard but not seen. Many reports of IBWOs had been accepted without question, leading to the dissemination of much erroneous information. Although it cannot be proven that IBWOs are not present, it is remotely possible that the birds that were reported were merely passing through the area where they were seen. The reported sightings of the IBWO in eastern Texas appear to be misidentifications, probably of pileated woodpeckers. I submitted a 31-page in-house report (P.W. Sykes, Jr., U.S. Fish and Wildlife Service, unpub. report, 1968), which included an appendix of 14 maps (portions of U.S. Geological Survey [USGS] topographic quadrangles showing the areas visited), documenting my findings to Ray Erickson, Harry Goodwin, and John Aldrich (zoologist, National Museum of Natural History, Washington, D.C.). On my return trip to the field station at Delray Beach, I stopped at Louisiana State University and briefly discussed my findings in East Texas with George Lowery and several of his graduate students.

George M. Heinzman and H. Norton Agey (Heinzmann [sic] and Agey, 1971; Heinzman's name is misspelled throughout the article), working on surveys for the Florida Audubon Society's Bald Eagle Conservation Project, covered more than 1 million acres in central Florida, mostly large cattle ranches. They had access to most of the private properties, and visited them as many as three or four times per year to document the status of activity at eagle nests. They reported sightings or vocalizations of IBWOs on 11 occasions from 1967 to 1969, with no reports in 1965 and 1966. They spent 41 days in the area where they reported the presence of IBWOs. I was invited to join them in 1968 and was asked not to divulge the search location. I honored that request for 43 years but, because no IBWOs have been reported from this particular location since 1969 and all principal parties are deceased, I believe it is now time to make the location known. The Heinzman and Agey



Comparison of pileated and ivory-billed woodpeckers showing ventral and dorsal views in flight and perched. From paintings by David Allen Sibley, well-known author and bird artist; used with permission.

IBWO reports were at a large cattle ranch with locked gates west of U.S. Route 27 in Hardee and Highlands Counties, north of Highlands Hammock State Park.

I visited the site with George and Norton on May 18 and 19, 1968. We did not see or hear any IBWOs. Prior to my visit, on January 21, 1968, the duo found a dead sweetgum (*Liquidambar styraciflua*) that exhibited a freshly excavated cavity whose entrance hole was 44 ft above ground. On April 21 they found the tree had fallen and its trunk had broken into pieces at the entrance hole. Measurements of the entrance hole and cavity were more characteristic of IBWO than of pileated woodpecker. Two down feathers were found in the cavity, and a white feather was found on the ground beside the entrance hole. The feathers were sent to the U.S. National Museum of Natural History (a part of the Smithsonian Institution), and the white feather was identified by Alexander Wetmore, former Secretary of the Smithsonian Institution and world-renowned ornithologist, as the innermost secondary feather of an IBWO. Dr. Wetmore commented that he could not positively identify the down feathers because no IBWO nestling specimens (this was prior to widespread use of deoxyribonucleic acid [DNA] analysis) were available for comparison (Heinzmann [sic] and Agey, 1971). Some years later, Jerome Jackson (Whiteker Eminent Scholar in Science at Florida Gulf Coast University, Naples, FL, oral commun., 1994) examined the white feather and agreed it was the innermost secondary feather of an IBWO. After George Heinzman died, Norton Agey kept the tree stub with the cavity for a while, then gave it to Byrum (Buck) W. Cooper (a birder and friend of Norton, living in Haines City, FL). Buck donated the tree stub to the Florida Museum of Natural History. The stub with the cavity (now reassembled) and the three feathers are still at the Florida Museum of Natural History on the campus of the University of Florida in Gainesville, where I have examined them several times.

In an interesting twist to this story, Jerome Jackson, while examining IBWO specimens at the Florida Museum of Natural History, found the innermost secondary feather missing from a female IBWO specimen collected in Florida in 1929. Is this an amazing coincidence or was fraudulent activity involved? We will probably never know with certainty. I can only say that George Heinzman and Norton Agey were friends of mine, and I do not believe they would commit such an act.

Heinzman and Agey recorded what they thought were vocalizations of an IBWO, but subsequent analysis at the Cornell Lab of Ornithology revealed them to be those of a pileated woodpecker. Samples from the base of the quill of the white secondary feather were sent to two laboratories for genetic analysis in 2005 to verify the identification as material from an IBWO. The results from the two labs were inconclusive (Andrew [Andy] W. Kratter, Florida Museum of Natural History, oral commun., about 2005). In addition to his position as Curator of Birds at the Florida Museum of Natural History, Andy served on the American Ornithologists' Union (AOU) Committee on Classification and Nomenclature, and formerly served on the American Birding Association's Checklist Committee. But, to my knowledge, the feathers have not been tested for arsenic or other preservatives that would have been used in preparation of a museum specimen to protect it in a collection.

I revisited the Green Swamp of Florida on October 1, 1969, with Gary Hickman (biologist, Bureau River Basins Office, Vero Beach, FL; later in his career he was USFWS regional director for Alaska, Anchorage). We covered areas in the Withlacoochee State Forest from the North, Center, and South Grade Roads, and a road extension off the Center Grade. On October 2, Gary and I covered areas on the north and south sides of the Withlacoochee River in the Green Swamp and some private lands along the river. Both days produced negative results.

During 1970, reports of IBWO came from South Carolina. From September 12 to 20, 1970, I searched in Scape Oer and Black Water Swamps and along the Congaree River with Bob and Liz Teulings, Evelyn Dabbs, Eli Parker, and Peggy Kilby. Bob Teulings is a coauthor of "Birds of the Carolinas" (Potter and others, 1980, 2006); Evelyn Dabbs at the time was the President of the Carolina Bird Club; Eli Parker was a local birder who claimed to have seen IBWOs in the Scape Oer Swamp (Sumter County) in all seasons pre-1970; and Peggy Kilby was a local birder. I soon discovered that Eli knew the pileated woodpecker quite well. The Teulings and I canoed 45 mi down the Congaree River starting just south of Columbia on September 15. On September 18, from Santee, the Teulings and I canoed 2 mi on the Congaree and 23 mi on the Wateree River. Evelyn Dabbs, the Teulings, and I searched a swamp area in the central part of the Francis Marion National Forest on September 19. The Scape Oer Swamp was searched on September 12, 13, 14, 17, and 20. In the course of searching I played a tape of the IBWO vocalizations, but we did not see or hear any IBWOs.

At the 1971 AOU meeting in Seattle, WA, Professor George Lowery of LSU had two color, slightly out-of-focus photographs, apparently taken with an inexpensive camera by someone he knew (see Jackson [2004] for details). The photos were believed to have been taken within a year or so of the meeting. I, along with several others, including Laurence (Laurie) C. Binford (California Academy of Science) and Burt L. Monroe, Jr. (professor of biology, University of Louisville, later to become chairman of the AOU's Committee on Classification and Nomenclature) were invited to view the photos. We went to Dennis R. Paulson's lab at the University of Washington to examine the photos more carefully. The images were small, but showed the correct color and markings of the IBWO. The bill and eyes were not visible, and we could not determine whether, in fact, the image was of a live bird. Nearly all those present were skeptical of the authenticity of the photos and the photographer. At that time Professor Lowery would not reveal the location where the photos were taken or the name of the person who took them. It was surmised by those present in Paulson's lab at the time that the location was somewhere in the Atchafalaya River Basin of southern Louisiana. Therefore, during the early 1970s, I acquired a set of USGS 7.5-minute quadrangles covering the entire Atchafalaya River Basin. I planned to fly over the region, identify the most promising areas on the quads, and check them by boat and on foot to determine whether IBWOs might still be present. Funding for this proposed project was not forthcoming, however, and the plan was abandoned.

From 1973 through 1984, I looked for IBWOs in peninsular Florida, including the Big Cypress area (now Big Cypress National Preserve); Fakahatchee Strand (now Fakahatchee Strand Preserve State Park); Ocala National Forest; Loxahatchee River; and Highlands Hammock, Myakka River, and Tomoka State Parks. I visited some of these areas several times without finding any sign of IBWO. From 1985 through 1999, I did not search for IBWOs, as I had transferred to Patuxent's Athens, GA, field station and was involved with other research projects. During this latter period I did not hear of any IBWO reports that sounded plausible.

On April 1, 1999 (April Fool's Day!), while hunting turkeys, David Kulivan, a graduate student at LSU, observed at close range what he thought was a pair of IBWOs in the Pearl River Wildlife Management Area (WMA). This area is on the Mississippi–Louisiana border, on the east side of Interstate 59 and just north of Slidell, LA. His description of the birds was excellent. This sighting was not made public for several weeks. Shortly after the news broke, I was contacted by Robert (Bob) P. Russell (biologist, USFWS, Minneapolis–St. Paul, MN) about a trip he was planning to search for IBWOs in the Pearl River WMA early in 2000, prior to leaf-out. In early February 2000, 10 people including Bob and I met at a motel in Slidell. For the next 10 days we (I was afield February 5–9) systematically searched for IBWOs in teams of two or three, with negative results except for Juliana Simpson (a birding friend of Bob Russell), who claimed to have heard and glimpsed an IBWO. This report was investigated immediately, but no IBWO was found. We concentrated our efforts in and around the site where Kulivan reported his sighting. The entire WMA is heavily hunted (only squirrel hunting was in season during our visit). A team search by the Cornell Lab of Ornithology in early 2002 did not find any IBWOs or any sign that they were present.

Several weeks prior to the dramatic public announcement of the rediscovery of IBWO by John (Fitz) W. Fitzpatrick (Director, Cornell Lab of Ornithology), Scott Simon (Director, Arkansas Chapter of The Nature Conservancy), Gale Norton (Secretary of the Interior), and others at Main Interior Building, Washington, D.C., on April 28, 2005, I received a telephone call from longtime birding friend Carl Perry in Pennsylvania that an IBWO had been observed in the Big Woods of eastern Arkansas. As all searching in 2004 and early 2005 had been kept secret, I was awestruck by this news. Carl had been tracking reports of IBWO sightings for several years and had developed an e-mail and telephone "grapevine" with many people throughout the southeastern United States. For details of the event, see Fitzpatrick (2005), Fitzpatrick and others (2005), Milius (2005), and Stokstad (2007).

I traveled to eastern Arkansas six times in search of the IBWO and looked for possible signs that it might be present. The earlier trips were on my own time and at my own expense, as as there was no funded project in place to support this work. The first trip was May 5–7, 2005, in the company of Steve Holzman (USFWS, Ecological Services, Athens, GA), Carl Perry, and Pierre D. Howard (birding friend, attorney, and former Lieutenant Governor of Georgia). We searched the Bayou de View sector of the Cache River National Wildlife Refuge (NWR) and environs, Brinkley, and Prairie Lake of the southeastern White River NWR and environs, Dagmar WMA, and Rex Hancock Black Swamp WMA. On this trip I became interested in woodpecker bill marks that were evident from bark scaling, and excavation of pits and furrows. On all subsequent trips I measured such bill marks.

On the second trip (June 30–July 2) I was accompanied by my wife, Joan. We visited Prairie Lake and Prairie Bayou, as well as other sites in the White River NWR. We were assisted by Richard E. Hines (refuge biologist), Jamie Kellum (refuge forester), and graduate students T.J. Benson and Nick Anich (Arkansas State University). We began to examine and measure the bill marks of pileated woodpeckers on trees where bark scaling and furrow excavations were present. We did this outside Arkansas to compare our observations with the features we had found at White River NWR.

On August 11–14, 2005, I visited Arkansas again. I traveled by canoe with M. David Luneau, Jr. (professor of electronics, University of Arkansas at Little Rock), on the Bayou de View north of State Route 17 on August 12. On April 25, 2004, David and his brother-in-law had inadvertently captured on video a distant, out-of-focus image of a large black and white woodpecker flying from behind the base of a tree. The camera was set on automatic and therefore was focused on the nearest object(s), which happened to be the handle of a canoe paddle and his brother-in-law's knee; consequently, the background with the bird was out of focus. This is the 4 seconds of video analyzed by the Cornell Lab, which concluded that the

Paul Sykes, U.S. Geological Survey, searching for the ivory-billed woodpecker in Bayou de View, AR, in 2005. Photo by Oron L. (Sonny) Bass, Jr., Everglades National Park.

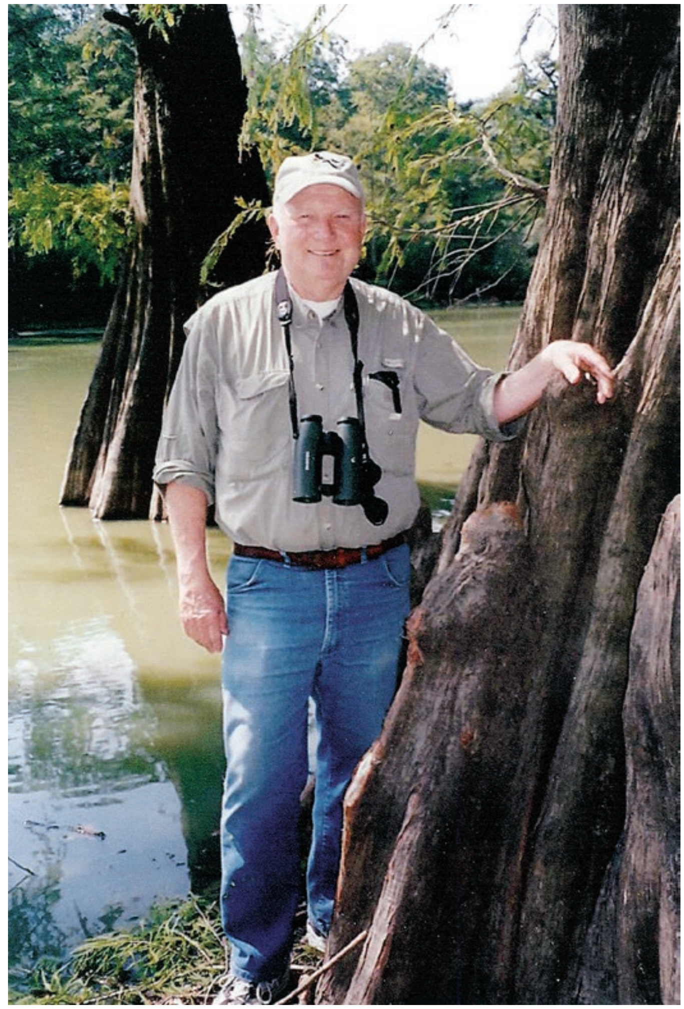
bird was an IBWO. Other locations visited on this trip were in the southern part of White River NWR.

Joan and I made a trip to Arkansas during September 28–31, and were assisted at the Cache River NWR by Ryan Mollnow, refuge biologist. We visited the George Tract, Biscoe Bottoms Unit, and east side of Bayou de View between State Route 17 and Interstate 40. Jacks Bay and Big Island in the White River NWR were searched September 30–31.

Carl Perry and I visited eastern Arkansas during January 11–15, 2006. We were joined on this trip by birding friends from Macon, GA, Tyrus (Ty) Ivey and Jerry and Marie Amerson. During the course of the trip, we visited points along Bayou de View, Areas A and B, Stabb Lake in the Cache River NWR, the Vera Denning property (we had permission to visit this private site), and The Nature Conservancy property at an area known as Boom Access. On January 14, I met Martjan Lammertink (woodpecker researcher from the Netherlands) and his wife Utami (both part of the Cornell search team), and we searched in the Boom Access area and examined bill marks on many trees, some of which I made impressions of using quick-setting mold putty. At this point, not having seen or heard an IBWO, I and others began to doubt the reliability of the reported sightings on the Bayou de View and in the surrounding areas.

A search was made at the Congaree National Park, SC, just south of Columbia, by Steve Holzman and me, together with Craig Watson (USFWS, Charleston, SC), Bill Hulslander (Park Resources Manager), Laurel Moore Barnhill (biologist, South Carolina Department of Natural Resources [now with the USFWS at Atlanta, GA]), Stuart Greeter (Realty Division, South Carolina Department of Natural Resources [DNR]), and birders Sherr Scott and Fran Rametta (South Carolina). We covered the elevated loop boardwalk area and the trail from Cedar Creek south to the Kingsnake Trail. Steve and I measured several large woodpecker bill marks on dead trees during the course of the day. No IBWOs were found, but a lot of fresh woodpecker feeding sign was noted. Joan and I visited the Congaree National Park again in April 2006. We covered the area of the boardwalk, but found no sign of the IBWO.

The sixth and final trip to eastern Arkansas was made by Steve Holzman and me on February 6–18, 2005, as part of the volunteer search team of Cornell Lab of Ornithology at White River NWR, with Tom Snetzinger (formerly with USFWS in Hawaii), as team leader. Other members of our crew were Kenneth (Ken) P. Able (California; retired professor of biology, State University of New York at Albany), Oron (Sonny) L. Bass (biologist, Everglades National Park), Keith Brady (a birder from Washington State), Walt D. Koenig (researcher, Hastings Natural History Reservation, CA, and former editor of "The Condor"), Melinda Welton (birder, Franklin, TN), and Larry White (birder, Evergreen, CO). Working in pairs, we searched the Prairie Lake area, Scrub Grass Bayou, Alligator Lake, Horseshoe Lake, the powerline right-of-way, Round Island, Prairie Lake Campground, the Lightbulb area, Jacks Bay, the levee south to the confluence of the White and Arkansas Rivers, and Dana Rockin. On February 12, Sonny, Keith, Walt, Steve, and I, in two borrowed canoes, searched the Bayou de View from State Route 17 south to the powerline and east to the Vera Denning property, but found no sign of IBWOs.



Paul Sykes, U.S. Geological Survey, during ivory-billed woodpecker surveys in the Congaree Swamp, SC, 2006. Photo by Joan Sykes, Watkinsville, GA.

Of interest, during the course of our 2 weeks at White River NWR, Sonny Bass discovered an albinistic pileated woodpecker that was seen for a period of 3 to 4 days. Several others of our group saw it, and the bird was photographed. Snyder and others (2009) stated that pileateds occasionally exhibit abberant extensive white wing patches closely resembling those of perched ivory-bills. Sometime in the late 1970s, Noel Snyder told me of seeing a pileated in south-central Florida with many of the secondary feathers being white. Therefore, some of the reports of ivory-bills in the southeastern United States could well have been part-albino pileateds.

When it was learned that IBWOs had reportedly been seen in the Choctawhatchee River Basin in northwestern

Florida in the winters of 2005 and 2006, Sonny Bass, Carl Perry, and I visited that area during July 23–28, 2006. Because the water level in the swamp was low at the time, we were able to cover areas on foot that are flooded in winter. Much to our surprise, people were riding jet skis and wave riders up and down the river. We searched Bruce Landing and Creek, Roaring Cutoff, the McCaskill Landing area, and boat landings on both sides of the river from U.S. Route 90 south to Florida State Highway 20 in a canoe borrowed from Steve Holzman. The three of us floated 40 mi on the Choctawhatchee River from Morrison Springs County Park south to Florida State Highway 20, including Dead River Landing, the powerline crossing of the river (both sides), Seven Runs Creek, Lost Lake, Little Lost Lake, and Tilley Landing. Most of our effort during this trip was concentrated around the powerline crossing, Bruce Creek, and Roaring Cutoff. No sign of IBWOs was found, but we did see many pileated woodpeckers, as well as their foraging marks on dead trees.

I visited the Choctawhatchee River on October 27–28, 2006, with Bob Russell and Gloria Rios (LaFalda, Argentina). We met Bobby W. Harrison (assistant professor of communications and arts, Oakwood University, Huntsville, AL) on October 26 at Ponce de Leon, FL, where we discussed IBWOs (Bobby and Tim W. Gallager, editor of the Cornell Lab's "Living Bird," and kayaker Gene M. Sparling, local guide, had reported seeing an IBWO on the Bayou de View on February 27, 2004). Bob, Gloria, and I watched under the powerline on the west bank of the Choctawhatchee River and searched the Morrison Springs area, Fox Hollow Drive off Route 284, Holmes Landing, and Dead River Landing, with negative results.

On my third trip to the Choctawhatchee River, Sonny Bass and I spent November 7–12, 2006, in the field. The deer hunting (gun) season opened during this visit, and the river bottom sounded like a shooting gallery. The entire river bottom is heavily hunted for game species; we found expended shell casings, camp sites, and trash throughout. We searched the west bank of the river at the powerline from U.S. Highway 90 downstream to Morrison Springs in Sonny's motorized canoe-boat. On foot, we checked the peninsula east of Morrison Springs downstream to Old Creek, covering more of the bottomland on foot because the water level was low. We took the canoe-boat from Dead River Landing through a series of small lakes to the main river course and from McCaskill Landing downstream to just north of Roaring Cutoff Island. We also hiked around Horseshoe Lake and followed the creek northeast to Carlisle Lake, took the canoe-boat from Florida State Highway 20 to the river, and traveled downstream to East River (which makes a loop off the east side of the Choctawhatchee River) and up East River, and checked Tilley and Bruce Creek Landings. At 10:05 a.m., we stopped for a break on the east side of the Choctawhatchee River about 1 mi upstream from the south end of East River. At 10:15 a.m., we heard three very loud sounds like an ax hitting a tree with great force at an estimated distance of 1,000 ft. We never saw what made the sounds, and we are certain no other people were in the area. The area is low and not suitable for camping. No IBWOs were detected on this trip.

My last trip looking for IBWOs in the western Florida Panhandle was from February 20 to March 2, 2007. The river level was very high at that time. I searched with Peter Range (refuge ranger, USFWS, Savannah River NWR Complex, GA) and Steve Calver (biologist, U.S. Army Corps of Engineers, Savannah, GA) on the powerline right-of-way on the west side of the river, the Bruce Creek area, and Grassey and McCaskill Landings; took Peter's boat upriver from McCaskill Landing to the Interstate 10 bridge; and searched Gum Creek Landing, the slough in the Oak Creek area, lower Carlisle Creek, Horseshoe Lake, and Cougar Island at Roaring Cutoff. Ken Able joined us in the search on February 22. We checked out Cow and Cedar Log Landings north of Morrison Springs along County Route 181C. We put in at Cedar Log Landing, paddled upstream about 1.5 mi, and stopped on the east bank to listen. At about 5:00 p.m., Peter reported he heard what sounded like kent calls in a series, but what actually made the calls was not seen. Steve and I heard nothing. Ken had gone by kayak to Lost Lakes. On February 25, birding friends Harry Armistead (Philadelphia, PA), Bob Ake (professor of chemistry, Old Dominion University, Norfolk, VA), and four others arrived to search for the woodpecker. On February 26, Peter, Steve, and I put the boat in at Cedar Log Landing and checked areas along the east side of the river opposite Old Creek, as well as the powerline right-of-way on the west side of the river. The next day we observed and listened at Horseshoe Lake; while we were there, John Puschock (professional bird guide, and owner and operator of Zugunruhe Birding Tours in Seattle, WA) came by in his kayak and stopped to discuss the IBWO situation. John had not seen or heard an IBWO since he started searching the Choctawhatchee River in early January 2007. John later told me he did not believe there were any IWBOs in the region.

During the last 5 days of this trip we spent a lot of time looking and listening on the west bank of the river at the powerline. This site is at a bend of the river. It provides a 0.5-mi view up and down the river and more than a 1-mi view across the swamp forest to the east, all the way to the upland. On February 28, in addition to the powerline area, Ken and I checked Tilley and Dead Lake Landings. At the latter, we spoke with Bobby Harrison and others. On March 1, Carl Perry joined Ken Able and me at the powerline on the east side of the river on the edge of the upland. We had permission to cross private land to reach this site. Many pileated woodpeckers are found in this area, as well as other places throughout the Choctawhatchee River bottoms. Also on March 1, Ken and I checked the boat landings south of Florida State Highway 20, including Bozman, Simpler's, and Rooks fish camps, Smoke House Lake, and Magnolia Landing. On March 2, my final day, Carl, Ken, and I watched and listened at the powerline. On this trip, no one in our group or whom we met in the area had ever observed an IBWO on the Choctawhatchee River.

Discussion

During the span of our searches for the IBWO in eastern Arkansas and northwestern Florida, the widths of bill marks made by foraging large woodpeckers on dead or dying trees were measured in these two states as well as Georgia, Maryland, Mississippi, North and South Carolina, Tennessee, and Virginia. These marks were measured on 19 species of hardwoods. The bill tips of 182 pileated and 178 ivory-billed woodpeckers were measured and the shape of bill tips noted at 15 museum collections. Posters illustrating measurements of the bill marks and bill tips of the two species have been presented at meetings at Patuxent (2005), AOU (University of California, Santa Barbara, 2005), Georgia Ornithological Society (Jekyll Island, GA, 2005), and at a Special Symposium—The Ecology of Large Woodpeckers: History, Status, and Conservation (Brinkley, AR, 2005).

Four cavities reported to be those of the IBWO are known to be extant in curated collections that my wife, Joan, and I examined. There is one such cavity at each of the following institutions: Museum of Comparative Zoology, Harvard University, Cambridge, MA; Cornell Lab of Ornithology, Ithaca, NY; Florida Museum of Natural History, University of Florida, Gainesville; and Anniston Museum of Natural History, Anniston, AL. The cavity at Cornell is the nest that Arthur A. Allen, Peter Paul Kellogg, and James T. Tanner studied in the Singer Tract in Louisiana in the mid-1930s. Their photographs of this nest, including the one on page 174 showing a male IBWO, were widely published.

After conducting several double-blind tests measuring the widths of bill marks made by large woodpeckers in bark scaling, excavation of nesting/roosting cavities, pits, and furrows on trees and examining the data, Steve Holzman and I found that the idea one might be able to determine whether such marks were made by either a pileated or an ivory-billed woodpecker was not possible as originally had been thought. There was too much variability in taking repeated measurements of the same bill mark by the same person or between different persons to be able to distinguish between the two species. There was also too much variability within marks made between individuals of the same species to be useful. Bill-mark widths also varied between tree species and state of tree decay, and there was a lot of variation in the shape and depth of the bill tips of specimens in museum collections both within and between the two species. So much for "pipe dreaming"—we had no smoking gun.

Through Judd A. Howell (director of Patuxent at the time), funding during the latter part of this project was made possible from the center's discretionary fund. Post-early 1970s and prior to funding, all searching was on my own time and at my own expense.

The history of the IBWO is well summarized by Jerry Jackson (2004) and Noel Snyder and others (2009). The David Luneau video, presented as proof of the existence of the IBWO in eastern Arkansas by John Fitzpatrick and associates in "Science" (Fitzpatrick and others, 2005, 2006), has been questioned by other investigators (Jackson, 2006; Jones and others, 2007; Sibley and others, 2006). I viewed David Luneau's 4-second clip three or four times. In my opinion, because the image is out of focus (when the original, small image was enlarged, it became pixelated), too little of the bird is visible, and the lighting is insufficient, the bird cannot be identified with any confidence.

My searches for the IBWO began in 1967 and continued intermittently through 2007. This effort has taken me to Florida, South Carolina, Louisiana, Texas, and Arkansas. Given the information contained in several reports from Florida, Texas, and Arkansas, I was certain I would see a living IBWO on at least four or five occasions, but it did not happen—I have never seen or heard the species in the wild, but have examined many study skins and mounts, and have listened to recordings of its vocalizations and double knocks made by Arthur A. Allen, Peter Paul Kellogg, and James T. Tanner.

It is impossible to say when the last living IBWO was seen in the United States. Although there are many reports of sightings over the past 70 years, there is no undisputed, verifiable proof of the bird's existence since the early 1940s. Invariably, whenever an IBWO sighting is in the news, there is a sharp spike in the number of sightings reported; the reports usually cease after a year or two. It is most unfortunate that so little effort to save the species was undertaken from the mid-1930s through at least the 1970s. Although it is obvious that the IBWO lost most of its habitat in the southeastern United States, I came to the conclusion many years ago that shooting of the birds for any number of reasons may have been the cause of its final demise. Noel Snyder (formerly with Patuxent conducting research on the California condor [*Gymnogyps californianus*] and snail kite) and associates came to a similar conclusion (Snyder and others, 2009), and they discuss the matter in detail.

James T. Tanner (1942; University of Tennessee, oral commun., 1968) and others that preceded him typically located IBWOs first by their calls or double knocks or raps, then followed the sounds to see the bird(s). In most of the reports made in the last several decades, the bird was either heard but not seen, or seen but not heard. These reports are contrary to accepted knowledge about how to locate the species. Furthermore, most observers saw only a fleeting glimpse of a large black and white bird flying away, did not have time to use binoculars or take a picture, typically observed under poor lighting conditions, had a view obstructed by vegetation or other objects, were searching alone, and so on.

Although several plausible sightings of IBWOs have been reported, it is puzzling to me why, if the bird still exists, no good-quality photos (film or digital) or video has been forthcoming. Likewise, all audio recordings of calls and double knocks have been of only common species or sounds resulting from nonliving events (gunshots), or were inconclusive with respect to the origin of the sound. I am unaware of any animal on the planet as large as the IBWO, living and flying about in habitat surrounded by a sea of humanity, that can escape detection, especially given the great effort expended in eastern Arkansas and northwestern Florida during 2004–06. It is also troubling to me that the bird repeatedly "is seen" and then cannot be refound. My long field experience over much of North America during the past 66 years tells me that something is amiss.

After the April 28, 2005, announcement about the rediscovery of the IBWO in the Big Woods of eastern Arkansas, and given the prestige of the agencies, institutions, organizations, and esteemed individuals involved, it is my opinion that most (perhaps as many as 95 to 99 percent) of the people who started searching for the bird believed that it was still alive and present in the area. I was in this camp for a while. Therefore, many searchers may have been subconsciously biased and, as a result, not sufficiently cautious in their identifications under field conditions. In other words, their perception was in error—and they did not actually see what they believed they saw. Field experience and skill levels with respect to bird identification also affect the accuracy of the identifications, particularly when species that are rare in a given area or species believed to be extinct or near extinct in a given area are found. Those who have extensive field experience with birds know that bird identification requires checking as many field marks as possible and repeating this process several times while viewing the bird. A brief glimpse or an otherwise poor view can result in misidentification. All birders make identification mistakes sooner or later; the point is to be as careful as possible in all identifications. In the words of English poet Alexander Pope, "To err is human…" On any bird search, enthusiasm and expectation can rule the day. The high degree of anticipation and excitement inherent in this modern-day hunt can sometimes override caution, which may be problematic in the search of the elusive ivory-billed woodpecker.

Acknowledgments

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References Cited

Catesby, Mark, 1731, Natural history of Carolina, Florida and the Bahama Islands: London, Benjamin White, v. 1, p. 16.

Dennis, J.V., 1948, A last remnant of ivory-billed woodpecker in Cuba: Auk, v. 65, no. 4, p. 497–507. [Also available at https://sora.unm.edu/node/19571.]

Fitzpatrick, J.W., 2005, The ivory-billed woodpecker still lives: Living Bird, v. 24, no. 3, p. 4–5.

Fitzpatrick, J.W., Lammertink, Martjan, Luneau, M.D., Jr., Gallagher, T.W., Harrison, B.R., Sparling, G.M., Rosenberg, K.V., Rohrbaugh, R.W., Swarthout, E.C.H., Wrege, P.H., Swarthout, S.B., Dantzker, M.S., Charif, R.A., Barksdale, T.R., Remsen, J.V., Jr., Simon, S.D., and Zollner, Douglas, 2005, Ivory-billed woodpecker (*Campephilus principalis*) persists in continental North America: Science, v. 308, no. 5727, p. 1460–1462. [Also available at http://dx.doi.org/10.1126/science.1114103.]

Fitzpatrick, J.W., Lammertink, Martjan, Luneau, M.D., Jr., Gallagher, T.W., and Rosenberg, K.V., 2006, Response to comment on "ivory-billed woodpecker (*Campephilus principalis*) persists in continental North America": Science, v. 311, no. 5767, p. 1555. [Also available at http://dx.doi.org/10.1126/science.1123581.]

Heinzmann, G.M., and Agey, H.N., 1971, The ivory-billed woodpecker found in central Florida: Florida Naturalist, v. 44, p. 46–47, 64.

Jackson, J.A., 2002, Ivory-billed woodpecker (*Campephilus principalis*), *in* Poole, A., and Gill, F., eds., The birds of North America: Philadelphia, PA, The Birds of North America, Inc., no. 711, 27 p. [Also available at https://birdsna.org/Species-Account/bna/species.ivbwoo.]

Jackson, J.A., 2004, In search of the ivory-billed woodpecker: Washington, D.C., Smithsonian Books, 295 p.

Jackson, J.A., 2006, Ivory-billed woodpecker (*Campephilus principalis*)—Hope, and the interfaces of science, conservation, and politics: Auk, v. 123, no. 1, p. 1–15. [Also available at http://dx.doi.org/10.1642/0004-8038(2006)123[0001:IWCPHA]2.0.CO;2.]

Jones, C.D., Troy, J.R., and Pomara, L.Y., 2007, Similarities between *Campephilus* woodpeckers double raps and mechanical sounds produced by duck flocks: Wilson Journal of Ornithology, v. 119, no. 2, p. 259–262. [Also available at http://dx.doi.org/10.1676/07-014.1.]

Milius, Susan, 2005, Comeback bird: Science News, v. 167, no. 24, p. 376–378. [Also available at https://www.sciencenews.org/article/comeback-bird.]

Potter, E.F., Parnell, J.F., and Teulings, R.P., 1980, Birds of the Carolinas (1st ed.): Chapel Hill, NC, University of North Carolina Press, 408 p.

Potter, E.F., Parnell, J.F., Teulings, R.P., and Davis, Ricky, 2006, Birds of the Carolinas (2d ed.): Chapel Hill, NC, University of North Carolina Press, 399 p.

Sibley, D.A., Bevier, L.R., Patten, M.A., and Elphick, C.S., 2006, Comment on "Ivory-billed woodpecker (*Campephilus principalis*) persists in continental North America": Science, v. 311, no. 5767, p. 1555. [Also available at http://dx.doi.org/10.1126/science.1122778.]

Stokstad, Erik, 2007, Gambling on the ghost bird: Science, v. 317, no. 5840, p. 888–892.

Snyder, N.F.R., Brown, D.E., and Clark, K.B., 2009, The travails of two woodpeckers—Ivory-bills and imperials: Albuquerque, NM, University of New Mexico Press, 170 p.

Tanner, J.T., 1942, The ivory-billed woodpecker: New York, National Audubon Society Report no. 1, 111 p.

Endangered Species Research in Hawaii: The Early Years (1965–87)

J. Michael Scott and Cameron B. Kepler

Hawaii is an ecologically isolated archipelago 2,500 miles from the nearest continent. Its isolation resulted in a taxonomically unbalanced flora and fauna with remarkable examples of adaptive radiation among those groups of organisms that won the dispersal sweepstakes. It was one of the last oceanic island groups to be populated by humans, about 900 A.D. by Polynesian travelers and in 1778 by Europeans. Relatively recent colonization by humans did not save it, however, from the biodiversity losses suffered by other isolated archipelagos—it only delayed them (Scott and others, 1988; Pratt and others, 2009a).

The size of those losses and the severity of the threats were formally recognized by the United States in 1964 with the publication of "Rare and Endangered Fish and Wildlife of the United States" by the U.S. Department of the Interior (DOI) Committee on Rare and Endangered Wildlife Species (U.S. Department of the Interior, 1964). Sixteen of the 62 species in that book, vertebrates all, were Hawaiian. That "red book" provided information that was used to compile the first formal list of endangered species under the 1966 Endangered Species Preservation Act, commonly referred to as "the Class of 67" (Wilcove and McMillan, 2006). That first list reinforced the findings of the Committee on Rare and Endangered Wildlife Species that Hawaii was home to some of the most highly endangered species in the United States. Twenty of the first 78 species listed under the Preservation Act (25.6 percent) were from Hawaii.

Dr. Ray Erickson was well aware of the challenges the country faced in recovering endangered species. A biologist in the Division of Research of the Bureau of Sport Fisheries and Wildlife in Washington, D.C., Dr. Erikson was a member of the Committee on Rare and Endangered Wildlife Species. Beginning in 1956, he had been advocating for funding to rear one of America's rarest birds, the whooping crane (*Grus americana*), in captivity and to conduct research on the sandhill crane (*Grus canadensis*) as its surrogate species. In early 1961, responding to a White House call for new ideas from Federal employees, Ray offered a proposal for a captive propagation and research program on rare and endangered species. Although small amounts of funding were received as early as that year to construct pens for sandhill cranes and support studies of their behavior in Colorado, funds sufficient to initiate a multispecies field and laboratory program to study rare and endangered species were not available until March 1966, when the Bureau signed off on $350,000 to support endangered wildlife research. With those funds, the research and captive propagation effort was moved to Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, from Monte Vista National Wildlife Refuge, Alamosa, CO, and Ray was placed in charge of what came to be known as the Endangered Wildlife Research Program. The original focus on captive rearing of whooping cranes and their surrogate the sandhill crane continued, but these efforts were quickly expanded to include other imperiled species and their surrogates, including black-footed ferret (*Mustela nigripes*), California condor (*Gymnogyps californianus*), Puerto Rican parrot (*Amazona vittata*), masked bobwhite quail (*Colinus virginianus ridgwayi*), and Aleutian Canada goose (*Branta canadensis leucopareia*) (U.S. Fish and Wildlife Service, 1976a, b; 1977). Ray Erickson originally envisioned an Endangered Wildlife Research Program that would include a field research component involving 10 field biologists that would complement the laboratory studies and captive propagation efforts at Patuxent. Four field biologists were eventually assigned to Hawaii. The first of these was Winston (Win) Banko. His task, as it was for all of us, was broad—work on the endangered birds of Hawaii. He arrived on Oahu in 1966, but later moved to the "Big Island" of Hawaii. John Sincock, who was assigned to Kauai, joined him in the islands in 1967. In 1974, Mike Scott joined Win Banko on the island of Hawaii, and, in 1977, Cam Kepler was assigned to Maui.

That first cohort of Patuxent's endangered species biologists in Hawaii, Banko, Kepler, Scott, and Sincock, conducted extensive studies on the endangered flora and fauna of the islands (see Selected References). Their studies involved reviews of the literature and museum collections to determine the extent of studies conducted and the historical distribution of each species, their status and distribution in the field (Scott and others, 1977), their natural history and ecology threats, and recovery planning. Simultaneously, they were developing the methods needed to accurately identify and rigorously assess the distribution and abundance of Hawaii's threatened and endangered species under the difficult conditions of complex terrain, adverse weather, and extremely low bird densities.

John Sincock, U.S. Fish and Wildlife Service, after surveying a Kau transect on Hawaii, summer 1976. Photo by U.S. Fish and Wildlife Service.

Jim Jacobi and Mike Scott, U.S. Fish and Wildlife Service, in Hawaii on the Kona side transect, summer 1978. Photo by U.S. Fish and Wildlife Service.

John Sincock, U.S. Fish and Wildlife Service, waiting for helicopter in Alaka'i Swamp, Kauai, 1983. Photo by Paul W. Sykes, Jr., U.S. Fish and Wildlife Service.

Several books that provide a synthesis of these and other efforts to save Hawaii's endangered avifauna and document the methods developed to survey and analyze the information from field studies emerged from the work of Patuxent's biologists and others in the islands. These included Ralph and Scott (1981), Scott and others (1986), Scott and others (1993), Scott and others (2002), Stone and Scott (1985), and Stone and Stone (1989). The importance of collaborations with other researchers from Federal and State agencies, nongovernmental organizations, and academia as well as the private landowners of Hawaii to the success of these efforts cannot be overstated. The list of those who worked with us in the field, helped with funding, and collaborated on almost every one of the publications that resulted from the U.S. Fish and Wildlife Service (USFWS) effort in the islands is long. One need only consider the institutional affiliations of the authors of the reports, journal articles, and books we wrote or edited and the individuals we recognized in the acknowledgments sections of each publication to gain an appreciation of the truly interdisciplinary and interinstitutional nature of our work in the islands.

The arrival of the first Patuxent researchers followed shortly after the arrival of Gene Kridler on Oahu in 1965. As the first DOI biologist and manager assigned to Hawaii, Gene played a key role in identifying research needs and obtaining funds to conduct the needed research. The late 1960s and early 1970s saw a great increase in research on the Hawaiian biota. Andrew Berger (ornithologist, American Museum of Natural History, New York) and his students at the University of Hawaii, other academic researchers, and folks at the Hawaii Department of Forestry and Wildlife (HDFW) were conducting life-history studies on many of the endemic birds (Berger and others, 1969; Engilis and Pratt, 1993; Frings, 1969; Shallenberger, 1977; Shallenberger and Vaughn, 1978; Swedberg, 1967). In 1970, the International Biological Program (Mueller-Dombois and others, 1981) initiated studies on island ecosystems and their biological organization. Finally, the U.S. Forest Service initiated studies on feather molting and behavior of Hawaiian birds (Ralph and Fancy, 1994) and the influence of nonnative species on native ecosystems (Scowcroft and Giffin, 1983). The role of Patuxent's four research biologists, working along with others, in that resurgence of interest in Hawaii's endangered biota is documented in the narrative that follows.

Win Banko came to the islands in 1966 and spent his first year on Oahu. He relocated to the island of Hawaii, where he established the Kilauea field station, a year later. Upon finding that little field work had been conducted on birds in Hawaii since the early 1900s (for example, Baldwin, 1945, 1947, 1953; Warner, 1960, 1967, 1968), Banko determined that his contribution to understanding the endangered species of Hawaii would be in examining the literature, long-forgotten field notes, and museum specimens to determine what information was already known and where the gaps in our knowledge lay. Early on, however, Win went into the field to survey the birds of Kipahulu Valley, Maui, where, as a member of The Nature Conservancy's Kipahulu expedition led by Rick Warner, he rediscovered the Maui nukupuu (*Hemignathus lucidus affinis*) (Warner, 1967; Banko, 1968). Banko also detected populations of several endangered forest bird species near Hawaii Volcanoes National Park. This discovery led to the selection of this area for intensive ecological studies by scientists associated with the International Biological Program and the U.S. Forest Service (Mueller-Dombois and others, 1981; Ralph and Fancy, 1994).

The bibliography on Hawaiian birds and the documentation and Banko's summaries of 20,700 status and distribution records were published by the Hawaii Cooperative Ecosystems Study Unit as part of its special reports series from 1980 to 1990. In addition to his library work, Win conducted field studies of Hawaiian crows (*Corvus hawaiiensis*) on the leeward side of Hawaii and searched for the endangered Hawaiian dark-rumped petrel (*Pterodroma sandwichensis*) and other seabirds high on the desolate volcanic slopes of Mauna Kea and Mauna Loa (Banko, 1980). His studies of the crow documented its precarious status and prompted the decision to bring the first Hawaiian crows into captivity for propagation. Those birds were housed in flight cages at Hawaii Volcanoes National Park for a short period, then transferred to State managers and used to form the nucleus of the Hawaiian crow captive propagation effort (National Research Council, 1992). Win retired from the USFWS in 1977.

Soon after his arrival in the islands in 1967, John Sincock conducted wetland surveys to identify possible sites for new wildlife refuges. John also initiated the first statistically rigorous inventories of endangered birds in the forested areas of Kauai (Sincock and others, 1984; Scott and others, 1986) and of the endangered birds of the Leeward Islands (Laysan, Midway, and Nihoa): Laysan finch (*Telospiza cantans*), Nihoa millerbird (*Acrocephalus familiaris kingi*), Nihoa finch (*Telospiza ultima*), and Laysan duck (*Anas laysanensis*). The Leeward Islands transects he established for the land bird inventories have been surveyed for more than 40 years (Conant and Morin, 2002; Morin and Conant, 1997). The wetland surveys of Kauai, conducted collaboratively by John with refuge manager Gene Kridler, provided the information needed to establish Hanalei, Huleia, and Kilauea Point National Wildlife Refuges and complemented the statewide waterfowl surveys by the HDFW (Engilis and Pratt, 1993). John expanded his research efforts to include natural history studies and threats to survival of three seabirds: Newell's shearwater (*Puffinus newelli*), band-rumped storm petrels (*Oceanodroma castro*), and Hawaiian dark-rumped petrels. After documenting the rediscovery of nesting areas for Newell's shearwaters (Sincock and Swedberg, 1969), he translocated eggs of this species under nesting wedge-tailed shearwaters (*Puffinus pacificus*) to secure low-elevation nesting areas at the then Kilauea Point National Administrative site (Byrd and others, 1984). Presumed offspring resulting from those efforts or their young still continue to nest on what is now Kilauea National Wildlife Refuge (http://www.fws.gov/endangered/news/bulletin-spring2009/shearwaters-of-kilauea-point.html).

Recognizing the heavy mortality suffered by Newell's shearwaters and Hawaiian dark-rumped and band-rumped storm petrels from crashing into the ground and other obstacles as a consequence of light pollution, John worked with Tom Telfer (HDFW) and researchers at the University of Wisconsin to develop methods to reduce light pollution by switching and shielding light sources (Reed and others, 1985; Telfer and others, 1987).

Left to right: Dave Marshall, Gene Kridler, and Win Banko, U.S. Fish and Wildlife Service, in Alaka'i Swamp, Kauai, HI, 1966. Photo by U.S. Fish and Wildlife Service.

Sincock and Tom Telfer established the Save Our Shearwaters (SOS) program in the 1970s. This project involved informing the island community of the consequences of the annual "raining of shearwaters" and its causes, and rescuing and then releasing stranded birds. Like almost every one of the Patuxent research studies, it quickly became a family affair when John's wife, Renate, took on many of the day-to-day activities of this effort—helping to enlist volunteers in the rescue effort, picking up birds, coordinating volunteers, and housing and releasing birds. The SOS program continues to this day (2016) under the auspices of the Kauai Humane Society (http://kauaihumane.org/services/saveourshearwaters).

John was the first to propose and then conduct an assisted colonization for the Northwest Islands passerines. Working with folks in the HDFW and with Gene Kridler of the USFWS, he successfully translocated Laysan finches to Pearl and Hermes Reefs. However, their efforts to translocate Nihoa finches to French Frigate Shoals were unsuccessful (Conant and Morin, 2002). One product of John's efforts in the Leeward Islands was a conservation plan for the future protection of the islands' endemic avifauna (Sincock and Kridler, 1977). John was the last of the original cohort of Patuxent research biologists to leave Hawaii. He left the islands and the USFWS in 1988.

Mike Scott arrived fresh from graduate school in the fall of 1974 to work with the endangered birds of Hawaii. Working with John Sincock, USFWS refuge manager Gene Kridler, and State wildlife biologists Ernie Kosaka, David Woodside, and Ronald Walker, he identified the information needs that were most important to recovering the endangered species of Hawaii. It was not the "niche differentiation studies of endemic Hawaiian birds" (MacArthur and Levin, 1961) that Mike had envisioned when he accepted the position of endangered species biologist with the USFWS. The questions to which managers needed answers were far more policy- and management-relevant. The decision-making process for recovery planning and implementation required answers to questions such as: Which species are extant? Where can they be found? How many are there? How do their distribution and density vary geographically? Who owns/manages the land, and what is its conservation status? The information gained from answering these questions could be used by managers to take the first two steps toward conserving Hawaii's endangered forest birds—identifying and securing essential imperiled species habitat. It became clear to Mike and his colleagues that to answer those questions an extensive survey of all remaining forest bird habitat in the islands was needed. The result of their planning was the Hawaiian Forest Bird Survey (HFBS), a program to survey all remaining forest bird habitat in the islands, from the tree line down to the cane fields or the coast, on all the main islands in Hawaii with the exception of Oahu. The forest birds of Oahu were surveyed separately by others (Shallenberger and Vaughn, 1978).

Prior to launching the HFBS in 1976, a population survey was conducted to determine the distribution and abundance of the palila (*Loxioides bailleui*). That effort was led by University of Hawaii graduate student Charles Van Riper, whereas Mike Scott and David Woodside of the HDFW took the lead on the multiagency effort. They laid transects throughout the dry mamane (*Sophora chrysophylla*) and naio (*Myoporum sandwicense*) forests of the upper elevations of Mauna Kea, where the last remaining palila resided (Van Riper and others, 1978). These surveys, covering the entire geographical, geophysical, and ecological range of the palila, were repeated in 1980, and have been repeated every year since then (Jacobi and others, 1996; Banko and others, 2009). That standard—the surveying of the entire range of a species—was used for the larger HFBS (described below) that followed.

With funding and administrative support from the management side of the USFWS, logistical support from Ernie Koska and others from the HDFW, and leadership from John Sincock and Mike Scott, this historic undertaking (Pratt and others, 2009a) was launched in the Kau Forest on the island of Hawaii in the spring of 1976 (U.S. Fish and Wildlife Service, 1976a, b; 1977) and concluded on the island of Kauai in the summer of 1981 (Scott and others, 1986). Observers were selected from applicants who were screened for birding experience, physical fitness, hearing acuity, birding ability, familiarity with Hawaiian birds, and ability to spend extended periods in remote locations to conduct field studies. All field folks were trained in distance estimation and the audio, behavioral, and visual characteristics of the forest birds of Hawaii, as well as safety and sampling protocols (Kepler and Scott, 1981; Ramsey and Scott, 1981; Scott and others, 1986). Members of that first year's survey team, particularly Jim Jacobi, provided input to the study design that resulted in adding surveys for mapping rare and endangered plants and increased documentation of feral animal presence to the survey protocols. To supplement the quantitative capabilities of the group, Scott asked Fred Ramsey, longtime friend, lifelong birder, and professor in the statistics department at Oregon State University, to join the team to provide the statistical and analytical rigor needed to fully analyze the survey findings (Ramsey and others, 1979, 1987; Ramsey and Scott, 1978, 1979, 1981).

By the time the last sampling station was surveyed, members of the HFBS had recorded 30 native species and 33 nonnative species; counted hundreds of thousands of birds; characterized vegetation (Jacobi, 1983, 1989; Jacobi and Scott, 1985); and documented the occurrence of nonnative plant species (Warshauer and others, 1983), damage from feral animals, the presence of rare plants, and the discovery of new ones (Warshauer and Jacobi, 1982) at 9,940 survey stations during 20,789 count periods along 876 miles of transects (Scott and others, 1986). A dozen or so new species of plants were described and much new information was gained on the distribution and abundance of rare plants from the botanical collections created by James Jacobi, Rick Warshauer, Holly McEldowney, and others. Throughout Mike's tenure in Hawaii, his wife, Sharon, played a key role in his research, making radio checks with field crews; picking up team members at the end of a transect; and serving as professional sounding board, editor, and all-around advisor for Mike.

The results of the HFBS were published in "Forest Bird Communities of the Hawaiian Islands" (Scott and others, 1986) and many other peer-reviewed publications that are described elsewhere. The 1986 synthesis received The Wildlife Society's Best Monograph Award. A review of the book characterized the HFBS as "a biological exploration of a high order and an excellent demonstration of applied statistics and despite my gloomy prediction, ecology of a high order…a model for other federal agencies charged with conservation programs" (Pimm, 1988). The complete electronic records of bird observation and transect locations of the HFBS are archived at the U.S. Geological Survey (USGS) Kilauea field station on the island of Hawaii (R.J. Camp, U.S. Geological Survey, written commun., 2010). The results of the HFBS complemented earlier statewide surveys of waterbirds (Engilis and Pratt, 1993; Reed and others, 2007; Swedberg, 1967) and game birds (Schwartz and Schwartz, 1949). Mike left Hawaii in 1984 to supervise the condor research effort in California.

Cam Kepler arrived in Maui in 1977 and joined the HFBS then underway on the Hamakua coast. Kepler participated in the surveys of Kona, Kohala, and Mauna Kea, including the extensive training sessions each spring (Kepler and Scott, 1981) in the years that followed. In 1980–81, he was coleader of the surveys of Maui, Molokai, Lanai, and Kauai.

During the HFBS, variable circle point counts for birds were conducted only in the first 4 hours of the day, weather permitting. This schedule provided time in the afternoons, after camp was set up, to make incidental observations in the study area. On May 12, 1981, during an incidental bird survey, Cam Kepler discovered the first nest of the small Kauai thrush (*Myadestes palmeri*) in a streamside cliff in one of the many embedded streams in the Alaka'i Swamp, on Kauai (Kepler and Kepler, 1983). All 13 small Kauai thrushes observed in the HFBS counts were also in deep gorges with flowing water, a finding consistent with observations made over 700 days in the Alaka'i by John Sincock (Scott and others, 1986). Knowledge of the microhabitats and nest-site locations of this endangered species allowed for more robust population estimates and management of the small Kauai thrush in subsequent years (Woodworth and others, 2009).

From 1977 to 1981, Cam and his wife, Kay Kepler, initiated surveys of several offshore islands to assess their seabird populations and plant communities (Kepler and Kepler, 1980; Kepler and others, 1984, 1990; Simons and others, 1985). All four islands hold breeding colonies of wedge-tailed shearwaters and Bulwer's petrels (*Bulweria bulwerii*). The information from the surveys was made available to the Hawaii Department of Land and Natural Resources (DLNR) to inform their management activities on the seabird islands.

In 1978 and 1979, Cam studied the water birds of Kealia and Kanaha Ponds on Maui. Kanaha Pond was protected as a State bird sanctuary, but the much larger Kealia Pond was privately owned. He found that most of the endangered Hawaiian stilts (*Himantopus mexicanus knudseni*) frequently left Kanaha to feed at Kealia, and that the two wetlands were strongly linked, both being essential to the survival of the stilt and Hawaiian coot (*Fulica alai*). In 1984, Cam was asked to provide biological information about Kealia to the Maui County Council, which was considering changing the wetland to a development district (harbor development was a possible use). Because of information provided by Cam and others (Shallenberger, 1977), Kealia was retained in conservation district zoning. Cam also provided his results to Federal and State agencies as well as nongovernmental organizations. After years of deliberation, the USFWS made plans to acquire Kealia Pond (http://www.fws.gov/kealiapond/) as a wildlife refuge.

In 1984, following completion of the HFBS, Cam initiated an expanded research program on the ecology of Hanawi's forest birds, including biological stresses affecting them. In 1986, Cam found the first nest of the po'o-uli (*Melamprosops phaeosoma*), and he, with Andy Engilis and Marie Ecton (USFWS), monitored this and a second (renesting) nest (Kepler and others, 1996; Engilis and others, 1996).

During their studies of the po'o-uli, the team noted a sobering increase in pig activity in the area (Mountainspring and others, 1990; Engilis, 1990). Habitat destruction by pigs resulted in soil loss of as much as 3 inches per year in Maui's primary watershed, far more than previously had been suspected. Cam's studies of the damage being caused by pigs to Hawaii's native ecosystems complemented those of others (Stone, 1985; Stone and Stone, 1989). This information and the briefings by Cam and others to media and public agencies alerted decision makers and the public to the threat pigs posed to endangered species and the public water supply.

During this same period, Haleakala National Park initiated a multimillion-dollar program to fence its entire holdings and expanded its ungulate control program (Pratt and others, 2009a). The Hawaii DLNR created the Hanawi Natural Area Reserve adjacent to The Nature Conservancy's Waikamoi Preserve, and both organizations initiated their own fencing and control programs (Price and others, 2009). Kepler traveled to Athens, GA, in 1987 to study Kirtland's warbler (*Setophaga kirtlandii*).

After Kepler left Hawaii, Patuxent maintained a research staff at the Kilauea field station that continued to study Hawaii's imperiled flora and fauna. That research is summarized in Scott and others (2002) and Pratt and others (2009a).

The Science Policy Discourse: Making a Difference in Policy and on the Ground

In addition to publishing their findings widely in scientific journals, Mike Scott and others made repeated presentations on the conservation implications of the HFBS and their other studies to the Hawaii Department of Forestry and

Wildlife and USFWS managers and biologists, as well as at many meetings of professional societies and conservation groups. By the late 1970s, word of the HFBS was spreading on the mainland and the conservation status of Hawaii's imperiled biota had attracted increased attention from The Nature Conservancy. The Nature Conservancy's Henry Little came to the islands in 1978. After becoming acquainted with the concept of the HFBS and its findings, he used the information from the HFBS to develop the Endangered Forest Bird Project. Working with Henry, Scott presented results of the HFBS and its implications for conservation of Hawaii's endangered biota to The Nature Conservancy's National Board of Directors in 1980. Funding for additional work by the Conservancy in Hawaii quickly became available. Henry used these funds to expand The Nature Conservancy's work in the islands.

In 1980, Henry hired Kelvin Taketa and Hardy Spoehr, and together they launched the Endangered Forest Bird Project (The Nature Conservancy, 1982). The objective of this project was to use the results of the HFBS and other research efforts in the islands to identify the areas critical to for the conservation of Hawaii's imperiled biota. The project's steering committee was composed of community leaders. Sincock, Scott, and Kepler served on the project's science advisory team along with National Park Service biologists and scientists from academia. In the fall of 1982, the Hawaii chapter of The Nature Conservancy was established. Henry Little quickly assembled a first-class board of trustees for the chapter, consisting of leaders in business, the nonprofit sector, and government. Realizing the importance of science-driven decision making, Henry Little tied the trustees to the science by using the Endangered Forest Bird Project's science advisory board and Cam Kepler's appointment to the Board of Trustees (1982–87) to bring science to the board's conservation actions decision-making process. This organizational structure ensured a powerful flow of ideas between formerly disparate parts of the Hawaiian conservation community and the scientific community. The science board identified and ranked important factors that were essential to the survival of Hawaii imperiled species (The Nature Conservancy, 1982, 1983, 1985), and gave that information to the Board of Trustees of the Hawaii chapter of The Nature Conservancy. The trustees quickly approved several areas for acquisition as nature reserves. The management challenges faced by the managers of those lands were identified in a "Save an Acre" commentary that was published in "Science" (Scott and Kepler, 1983). The response was phenomenal. By 1984, more than $4 million for conservation of endangered forest bird habitat had been brought into Hawaii, mostly in response to the information provided by the HFBS. Henry and Kelvin received the DOI Conservation Service Award in 1984 for their conservation efforts in Hawaii.

While The Nature Conservancy was conducting its conservation activities, Hawaii's Natural Area Reserve System was identifying possible areas for designation as Natural Areas and the USFWS was screening areas for possible new wildlife refuges. The conservation efforts of these three groups were not entirely independent of each other, and each used shared resources to inform its decisions regarding establishment and design of new ecological reserves. Those decisions, made with the benefit of information from the HFBS and other sources, led to the designation of 12 protected areas, including the USFWS Hakalau Forest National Wildlife Refuge (http://www.fws.gov/refuge/hakalau_forest) and an area in Kipahulu Valley on Maui that later became part of Haleakala National Park. Other Natural Area Reserves were established both independently and collaboratively by the Hawaii DLNR and The Nature Conservancy. These areas include Pu'u Maka'ala (http://dlnr.hawaii.gov/ecosystems/nars/hawaii-island/puu-makaala/) and Pu'u O Umi Natural Area Reserves (http://dlnr.hawaii.gov/ecosystems/nars/hawaii-island/puu-o-umi-3/) on the island of Hawaii (Scott and others, 1987b). The Nature Conservancy and the State established Waikamoi Preserve (http://www.nature.org/about-us/index.htm?intc=nature.tnav.about) and the 7,500-acre Hanawi Natural Area Reserve (http://dlnr.hawaii.gov/ecosystems/files/2013/07/Hanawi-Management-Plan.pdf) on Maui. The Nature Conservancy established Kamakou Preserve (http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/hawaii/placesweprotect/kamakou.xml) and Pelekunu (http://dlnr.hawaii.gov/ecosystems/files/2013/09/Pelekunu-LRP-DRAFT-FINAL.pdf), Olokui (http://dlnr.hawaii.gov/ecosystems/nars/reserves/molokai/olokui/), and the 1,330-acre Puu Ali'i Natural Area Reserves (http://dlnr.hawaii.gov/ecosystems/nars/reserves/molokai/puu-alii/) on Molokai.

On the island of Kauai, the 213-acre Kaluahonu Preserve easement to protect nesting sites of Newell's shearwater (http://www.abcbirds.org/conservationissues/habitats/BCR/hawaii.html) and the 3,579-acre Hono O Na Pali Natural Area Reserve (http://hawaii.gov/dlnr/dofaw/nars/reserves/kauai/honoonapali) to conserve forest birds and rare plants were established. These and several other previously mentioned nature reserves on Kauai were established, in part, because of information provided by the work of Patuxent's research biologists and their conservation partners.

The key to the quick application of information from the survey to the establishment of new protected areas for forest birds was the collaborative development of management- and policy-relevant research questions with managers and the continued involvement of the managers in conducting the survey, making the information available to decision makers in a user-friendly way (The Nature Conservancy, 1982, 1983, 1985; Scott and others, 1986). The use of graphics showing the lack of overlap in the areas established and managed for their conservation value and the distribution of the birds of conservation interest was a particularly powerful tool (Scott and others, 1987b, 1993).

Many of the tools used in the HFBS have been used by others. The gap analysis process, first used as a means to identify gaps in the protected areas network for endangered

Hawaiian birds (Scott and others, 1987a; Scott and others, 1993), is used worldwide to assess the conservation status of species and ecosystems (Rodrigues and others, 2004a, b; see also http://gapanalysis.usgs.gov/about-gap/our-history/). Every signatory to the Convention on Biological Diversity Treaty (http://en.wikipedia.org/wiki/Convention_on_Biological_Diversity) uses gap analysis to identify gaps in protection of their biological resources (http://www.cbd.int/doc/publications/cbd-ts-24.pdf), and GAP is an established program in the USGS (http://gapanalysis.usgs.gov/). Variable circular plots are widely used to estimate bird numbers (Estades and Temple, 1999). The 1980s rare bird surveys of the Micronesian Islands by John Engbring (USFWS), Fred Ramsey, and others used the methods and protocols of the HFBS to census the imperiled birds of Rota, Tinian, Aguijan, and Saipan (Engbring and others, 1986).

The translocation of Nihoa finches to new locations in the Leeward Islands by John Sincock and others was unsuccessful, but a population of Laysan finches persists today (2016) on Pearl and Hermes Atoll because of a 1967 introduction by John and Gene Kridler (Morin and Conant, 1997; Conant and Morin, 2002). Newell's shearwater can be found today at Kilauea Point National Wildlife Refuge on Kauai (http://www.fws.gov/endangered/news/bulletin-spring2009/shearwaters-of-kilauea-point.html) because of the translocation efforts of John and others. Those early translocation efforts in the Leeward Islands and Kauai demonstrated the results that could be achieved, and provided a model for the recent translocation efforts to decrease the risk of extinction for Laysan ducks (*Anas laysanensis*) and Nihoa millerbirds (*Acrocephalus familiaris kingi*) (Reynolds and others, 2008; U.S. Fish and Wildlife Service, 2014).

Finally, the Hawaiian crow is known to occur only in captivity (Banko, 2009; Lieberman and Kuehler, 2009). Its future as a wild bird lies with the captive flock made possible through the early efforts of Ernie Kosaka, Ah Fat Lee, Fern Duvall, and others in the HDFW and Win Banko to ensure that there would be options for the Hawaiian crow's survival (http://blogs.sandiegozoo.org/2009/04/21/hawaii-bird-program-open-house).

Our work in Hawaii differed in several ways from that done elsewhere in Patuxent's Endangered Species Program. First, we were tasked with studying an entire avifauna, whose life histories, distribution and ecology, and indeed very existence were undocumented, whereas other programs focused only on a single species. In response to this challenge, we pioneered the development of ecosystem recovery plans for Hawaii's birds (Kepler and others, 1984; Scott and others, 1984; Sincock and others, 1984) rather than the single-species plans that were the standard in the 1970s and 1980s. We also developed new approaches for detecting and monitoring rare birds (Reynolds and others, 1980; Ramsey and others, 1979); however, the clinical interventions and captive propagation of individual animals that were a major component of many of Patuxent's other endangered species field research efforts were only a minor part of ours.

Where Do We Go From Here?

Nearly 50 years after the first endangered species research biologists arrived in the islands, what have we learned? As a result of the work of Patuxent's biologists and other researchers from State and Federal agencies, nongovernmental organizations, and academia in the islands, we learned a lot about the rare things. We learned where they are and where they are not; new sampling methods for rare species; distribution, abundance, habitat associations, and biology of rare species; the nature of threats to survival of Hawaii's endangered birds and plants; and the management actions needed to mitigate those threats. The take-away lessons from those early research efforts are sobering: recovery is slow and asking conservation-relevant research questions is a difficult process, but using the results of that research in a timely manner in the field to implement management actions at scales that increase the survival chances of a species is much more so. Our most important lesson may have been that the consequences of delaying or not implementing management actions are often irreversible.

The birds of Hawaii are still highly endangered (Gorresen and others, 2009; Pratt and others, 2009b). None of the birds unrecorded or insufficiently documented during the HFBS was reliably reported after the survey (Gorresen and others, 2009). The chances that the unreported birds—for example, Kauai nukupuu (*Hemignathus lucidus hanapepe*) and Kauai akialoa (*Hemignathus ellisianus stejengeri*)—escaped detection are vanishingly small (Elphick and others, 2010; Gorressen and others, 2009; Reynolds and others, 2002; Scott and others, 1986, 2008; Sykes and others, 2000). Several birds observed during the HFBS—for example,'o'u (*Psittirostra psittacea*) (Kauai and Hawaii), Kauai 'o'o (*Moho braccatus*), large Kauai thrush (*Myadestes myadestinus*), Molokai thrush (*Myadestes lanaiensis rutha*), Maui akepa (*Loxops coccineus ochraceus*), Maui nukupuu, and po'o-uli—as well as the Oahu creeper (*Paroreomyza maculata*) observed on Oahu during surveys by Shallenberger and Vaughn (1978) have not been seen for 10 or more years. As mentioned above, one species, the Hawaiian crow, is known to occur only in captivity.

Why are these birds still endangered? For many of the species we were tasked with saving, we failed to eliminate or mitigate threats and restore habitat at temporal and spatial scales consistent with achieving recovery goals. The consequence of our failure to act at the necessary scales and speed to reduce threats was often extinction. None of the putatively "extinct" species, save possibly the po'o-uli (Groombridge, 2009; Woodworth and others, 2009), benefited from the well-funded and intensive rescue efforts mounted for species like the California condor or peregrine falcon (*Falco peregrinus*). The work forces involved in several of those mainland conservation efforts commonly were larger than the population of the endangered species they were attempting to save. Unfortunately, for many other endangered Hawaiian birds, the resources to implement needed conservation efforts were not available and many of the management actions identified in the first recovery plans were not implemented or were implemented at scales that were not conservation-relevant.

For example, the first Kauai Forest Bird Recovery Plan (Sincock and others, 1984) called for removal of feral ungulates from the Alaka'i Swamp, the heart of the last remaining habitat for Kauai's endangered forest birds, but the first ungulate fences were not built until 27 years later (http://dlnr.hawaii.gov/ecosystems/files/2013/08/Proposal-Extension-of-Hono-o-Na-Pali-NAR.pdf). In the intervening three decades, three species on Kauai—Kauai 'o'o, the 'o'u, and the large Kauai thrush—have become extinct and two new species have been listed.

Similarly, the 1986 recovery plan for the palila called for removal of feral ungulates from critical habitat of the palila, a recommendation that was supported by two court decisions (Juvik and Juvik, 1984; Meltz, 1994). Twenty-six years later, although our knowledge of the ecology and biology of the palila has increased substantially (Banko and others, 2009), mouflon (*Ovis gmelini musimon*) are still found in critical habitat of the palila in large numbers and are being managed as a recreationally sustainable population for hunters, in part with Federal funds provided under the Pittman-Robertson Act (https://www.fws.gov/laws/lawsdigest/FAWILD.HTML).

Why was there a failure to implement management actions that were known to prevent extinction and promote recovery (Kepler and others, 1983; Scott and others, 1984; Sincock and others, 1984)? Current recovery efforts in Hawaii, the state with the highest density of endangered species per acre in the country, lag far behind those in other states in terms of conservation funds received. Hawaiian terrestrial vertebrates, 30 species, received $1.7 million, with 5 species (the Hawaiian crow, Hawaiian common moorhen [*Gallinula chloropus sandvicensis*], Newell's shearwater, po'o-uli, and Hawaiian stilt) receiving 78 percent of those funds spent on Hawaii's terrestrial vertebrates (U.S. Fish and Wildlife Service, 1996).

The situation is more complex than a lack of funds, however. In a thoughtful treatment of this question, David Leonard and others have suggested that lack of funding (Leonard, 2008; Restani and Marzluff, 2002), lack of understanding of the plight of endangered birds in the islands, and failure to convince folks of the plight have contributed to an urgent need for conservation action. Additionally, there are substantial sociopolitical barriers to implementing conservation actions to benefit endangered forest birds related to conflicting management objectives for areas where endangered species occur (for example, sustaining a recreationally viable population of mouflon for hunters as opposed to maintaining the integrity, diversity, and health of palila habitat [Banko and others, 2009]).

Where do we go from here? We have the advantage of nearly 50 years of research and the wisdom and insights gained from four decades of management actions, successful and unsuccessful; revised recovery plans for all but the northwestern passerine species; and a larger and more diverse conservation constituency with thousands of interested citizens and new citizen conservation groups (the Hawaii Conservation Alliance [http://hawaiiconservation.org/], Hawaii Association of Watershed Partnerships [http://hawp.org/], and Hawaiian Wetland Joint Venture [http://pcjv.org/hawaii/]) with which to work. These new institutional structures focused on maintaining the integrity of native ecosystems and their ecological processes will provide new perspectives on what actions are needed to save the remainder of Hawaii's endangered ecosystems and species (Pratt and others, 2009b). Fortunately, working with the broader conservation perspectives offers new hope for the future of Hawaii's endemic flora and fauna.

The ability of these conservation efforts to prevent extinction of additional species has been made more difficult, however, because of climate change, the increase in human population, and the need to act at landscape scales (Price and others, 2009). Finally, success will require more bridge building and collaboration among different constituencies, and major new commitments of collaboration and financial resources.

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Aloha from Hawaii—John Sincock and his assistant, Mike Scott, U.S. Fish and Wildlife Service, in their truck at the end of several days' work, summer 1976. Photo by U.S. Fish and Wildlife Service.

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Selected References

Baldwin, P.H., 1945, The Hawaiian Goose, its distribution and reduction in numbers: Condor, v. 47, no. 1, p. 27–37. [Also available at https://sora.unm.edu/node/99579.]

Baldwin, P.H., 1947, The life history of the Laysan Rail: Condor, v. 49, no. 1, p. 14–21. [Also available at https://sora.unm.edu/node/99790.]

Baldwin, P.H., 1953, Annual cycle, environment and evolution in the Hawaiian honeycreepers (Aves: Drepaniidae): University of California Publications in Zoology, v. 52, no. 4, p. 285–398.

Banko, P.C., 2009, ʻAlalā, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 473–486.

Banko, P.C., Brinck, K.W., Farmer, Chris, and Hess, S.C., 2009, Palila, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 513–522.

Banko, W.E., 1968, Rediscovery of the Maui nukupuu, *Hemignathus lucidus affinis*, and sighting of Maui parrotbill, *Pseudonestor xanthophrys*, Kipahulu Valley, Maui, Hawaii: Condor, v. 70, no. 3, p. 265–266. [Also available at https://sora.unm.edu/node/101761.]

Banko, W.E., 1972, Bibliography of Hawaiian birds exclusive of the ʻElepaio, Mauna Loa Field Station: U.S. Fish and Wildlife Service, Hawaii Volcanoes National Park, HI, 87 p.

Banko, W.E., 1979a, History of endemic Hawaiian birds—Introduction: CPSU/UH Avian History Report 1, Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, 14 p. [Also available at http://hdl.handle.net/10125/329.]

Banko, W.E., 1979b, History of endemic Hawaiian birds—Specimens in museum collections: CPSU/UH Avian History Report 2, Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, 80 p. [Also available at http://hdl.handle.net/10125/333.]

Byrd, G.V., Sincock, J.L., Telfer, T.C., and Moriarity, D.I., 1984, Cross-fostering experiment with Newell's race of Manx shearwater: Journal of Wildlife Management, v. 48, no. 1, p. 163–168. [Also available at http://www.jstor.org/stable/3808464.]

Berger, A.J., Eddinger, C.R., and Frings, S.C., 1969, The nest and eggs of the anianiau: Auk, v. 86, no. 2, p. 183–187. [Also available at https://sora.unm.edu/node/21847.]

Clapp, R.B., Kridler, Eugene, and Fleet, R.R., 1977, The natural history of Nihoa Island, Northwestern Hawaiian Islands: Atoll Research Bulletin, no. 207, 147 p. [Also available at http://www.sil.si.edu/DigitalCollections/atollresearchbulletin/ARB_RecordSingle.cfm?issue=207.]

Conant, Sheila, and Morin, M.P., 2002, Laysan finch and Nihoa finch, *in* Poole, A., and Gill, F., eds, The birds of North America, no. 639: Philadelphia, PA, The birds of North America, Inc., 32 p. [Also available at http://bna.birds.cornell.edu/bna/species/639a/articles/introduction and http://bna.birds.cornell.edu/bna/species/639b/articles/introduction.]

Conant, Sheila, Pratt, H.D., and Shallenberger, R.J., 1998, Reflections on a 1975 expedition to the lost world of the alaka'i and other notes on the natural history, systematics, and conservation of Kauai birds: Wilson Bulletin, v. 110, no. 1, p. 1–22. [Also available at https://sora.unm.edu/node/131535.]

Elphick, C.S., Roberts, D.L., and Reed, J.M., 2010, Estimated dates of recent extinctions for North American and Hawaiian birds: Biological Conservation, v. 143, no. 3, p. 617–627. [Also available at http://www.sciencedirect.com/science/article/pii/S0006320709004911.]

Engbring, John, Ramsey, F.L., and Wildman, V.J., 1986, Micronesian forest bird survey, 1982—Saipan, Tinian, Aguiguan, and Rota: U.S. Fish and Wildlife Service Report, 143 p.

Engilis, Andrew, Jr., 1990, Field notes on native forest birds in the Hanawi Natural Area Reserve, Maui: ʻElepaio, v. 50, no. 8, p. 67–72.

Engilis, Andrew, Jr., and Pratt, T.K., 1993, Status and population trends of Hawaii's native water-birds, 1977–1987: Wilson Bulletin, v. 105, no. 1, p. 142–158. [Also available at https://sora.unm.edu/node/131082.]

Engilis, Andrew, Jr., Pratt, T.K., Kepler, C.B., Ecton, A.M., and Fluetsch, K.M., 1996, Description of adults, eggshells, nestling, fledgling, and nest of the po'o-uli: Wilson Bulletin, v. 108, no. 4, p. 607–619. [Also available at https://sora.unm.edu/node/131423.]

Estades, C.F., and Temple, S.A., 1999, Deciduous-forest bird communities in a fragmented landscape dominated by exotic pine plantations: Ecological Applications, v. 9, no. 2, p. 575–585. [Also available at http://www.jstor.org/stable/2641145.]

Frings, S.C., 1967, The natural history of the Hawaiian 'Elepaio—A review of the literature: 'Elepaio, v. 27, no. 12, p. 108–111.

Giffin, J.G., Scott, J.M., and Mountainspring, Stephen, 1987, Habitat selection and management of the Hawaiian crow: Journal of Wildlife Management, v. 51, no. 2, p. 485–494. [Also available at http://www.jstor.org/stable/3801038.]

Gorresen, P.M., Camp, R.J., Reynolds, M.H., Woodworth, B.L., and Pratt, T.K, 2009, Status and trends of native Hawaiian songbirds, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 108–136.

Groombridge, 2009, Po'o-uli, *in* Pratt, T.K., Atkinson, C., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 487–498.

Jacobi, J.D., 1978, Vegetation map of the Kau Forest Reserve and adjacent lands of Hawaii: U.S. Forest Service Resource Bulletin PSW 16, 3 p. booklet and plate. [Also available at https://archive.org/details/IND79069444.]

Jacobi, J.D., 1989, Technical report 68—Vegetation maps of the upland plant communities on the islands of Hawaii, Maui, Molokai, and Lanai: Honolulu, HI, University of Hawaii at Manoa, 25 p. [Also available at http://manoa.hawaii.edu/hpicesu/techr/068.pdf.]

Jacobi, J.D., and Scott, J.M., 1985, An assessment of the current status of native upland habitats and associated endangered species on the island of Hawai'i, *in* Stone, C.P., and Scott, J.M., eds., Hawai'i's terrestrial ecosystems—Preservation and management: Honolulu, HI, University of Hawaii, p. 3–22. [Also available at http://www.hear.org/books/hte1985/pdfs/hte1985.pdf.]

Jacobi, J.D., Fancy, S.G., Giffin, J.G., and Scott, J.M., 1996, Long-term population variability in the palila, an endangered Hawaiian honeycreeper: Pacific Science, v. 50, no. 4, p. 363–370. [Also available at http://hdl.handle.net/10125/2910.]

Juvik, J.O., and Juvik, S.P., 1984, Mauna Kea and the myth of multiple use—Endangered species and mountain management in Hawaii: Mountain Research and Development, v. 4, no. 3, p.191–202. [Also available at http://www.jstor.org/stable/3673140.]

Kepler, C.B., Burr, Tim, Cooper, C.B., Dunatchik, Dave, Medeiros, Joseph, Scott, J.M., Ueoka, Meyer, and Wong, Wesley, 1984, Maui-Molokai Forest Birds Recovery Plan, May 1984: Portland, OR, U.S. Fish and Wildlife Service, 110 p. [Also available at https://babel.hathitrust.org/cgi/pt?id=mdp.39015024958426.]

Kepler, C.B., and Kepler, A.K., 1980, The birds of Molokini Island, Maui: 'Elepaio, v. 40, no. 11, p. 147–151.

Kepler, C.B., and Kepler, A.K., 1983, A first record of the nest and chicks of the small Kauai thrush: Condor, v. 85, no. 4, p. 497–499. [Also available at http://sora.unm.edu/node/103397.]

Kepler, C.B., Kepler, A.K., and Simons, T.R., 1984, Hawaii's seabird islands, No. 1—Moke'ehia: 'Elepaio, v. 44, no. 7, p. 71–74.

Kepler, C.B., Kepler, A.K., Simons, T.R., Hobdy, B., and Simons, P.M., 1990, Hawaii's seabird islands, No. 3—Moku-Ho'Oniki and Kanaha Rock, Molokai: 'Elepaio, v. 50, no. 9, p. 75–81.

Kepler, C.B., Pratt, T.K., Ecton, A.M., Engilis, Andrew, Jr., and Fluetsch, K.M., 1996, Nesting behavior of the po'o-uli: Wilson Bulletin, v. 108, no. 4, p. 620–638. [Also available at http://sora.unm.edu/node/131424.]

Kepler, C.B., and Scott, J.M, 1981, Reducing bird count variability by training observers, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 366–371. [Also available at https://sora.unm.edu/node/49.]

Leonard, D.L., Jr., 2008, Recovery expenditures for birds listed under the U.S. Endangered Species Act—The disparity between mainland and Hawaiian taxa: Biological Conservation, v. 141, no. 8, p. 2054–2061. [Also available at http://www.sciencedirect.com/science/article/pii/S0006320708002085.]

MacArthur, Robert, and Levin, Richard, 1967, The limiting similarity, convergence and divergence of coexisting species: American Naturalist, v. 101, no. 921, p. 377–385. [Also available at http://www.jstor.org/stable/2459090.]

Meltz, Robert, 1994, Where the wild things are—The Endangered Species Act and private property: Environmental Law, v. 24, p. 369–417. [Also available at http://heinonline.org/HOL/Page?handle=hein.journals/envlnw24&g_sent=1&collection=journals&id=397.]

Morin, M.P., Conant, Sheila, and Conant, Patrick, 1997, Laysan and Nihoa millerbird, *in* Poole, A., and Gill, F., eds., The Birds of North America, no. 302: Philadelphia, PA, The Birds of North America, Inc., 29 p. [Also available at http://bna.birds.cornell.edu/bna/species/302/articles/introduction.]

Mountainspring, Stephen, Casey, T.L.C., Kepler, C.B., and Scott, J.M., 1990, Ecology, behavior and conservation of the poo-uli (*Melamprosops phaesoma*): Wilson Bulletin, v. 102, no. 1, p. 109–122. [Also available at https://sora.unm.edu/node/130788.]

Mountainspring, Stephen, and Scott, J.M., 1985, Interspecific competition among Hawaiian forest birds: Ecological Monographs, v., 55, no. 2, p. 219–239. [Also available at https://www.jstor.org/stable/1942558.]

Mueller-Dombois, Dieter, Bridges, K.W., and Carson, H.L., eds., 1981, Island ecosystems—Biological organization in selected Hawaiian communities: Stroudsberg, PA, Hutchinson–Ross Publishers, 583 p.

National Research Council, 1992, Scientific bases for the preservation of the Hawaiian crow: Washington, D.C., National Research Council, 148 p. [Also available at http://www.nap.edu/read/2023/.]

Pimm. S.L., 1988, Forest bird communities of the Hawaiian Islands—Their dynamics, ecology, and conservation, by J.M. Scott, Stephen Mountainspring, F.L. Ramsey, and Cameron Kepler (book review): Auk, v. 105, no. 2, p. 400-402. [Also available at http://www.jstor.org/stable/4087519.]

Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., 2009a, Conservation biology of Hawaiian forest birds—Implications for island fauna: New Haven, CT, Yale University Press, 707 p.

Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., Woodworth, B.L., and Mehrhoff, L.A., 2009b, Can Hawaiian forest birds be saved?, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C, Jacobi, J.D., and Woodworth, B.L., eds. Conservation biology of Hawaiian forest birds—Implications for island fauna: New Haven, CT, Yale University Press, p. 552–580.

Pratt, T.K., Kepler, C.B., and Casey, T.L.C., 1997, Poouli (*Melamprosops phaeosoma*), *in* Poole, A., and Gill, F., eds., the Birds of North America, no. 272: Philadelphia, PA, Academy of Natural Science, and the Washington, D.C., American Ornithologists' Union, 16 p. [Also available at http://bna.birds.cornell.edu/bna/species/272/articles/introduction.]

Price. J.P., Jacobi, J.D., Pratt, L.W., Warshauer, F.R., and Smith, C.W., 2009, Protecting forest bird populations across landscapes, *in* Pratt, T.K., Atkinson, C.T., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island fauna: New Haven, CT, Yale University Press, p. 381–404.

Ralph, C.J., and Fancy, S.G., 1994, Timing of breeding and molting in six species of Hawaiian honeycreepers: Condor, v. 96, no. 1, p. 151–161. [Also available at http://sora.unm.edu/node/104830.]

Ralph, C.J., and Scott, J.M., 1981, Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, 630 p. [Also available at https://sora.unm.edu/node/49.]

Ramsey, F.L., and Scott, J.M., 1978, Use of circular plot surveys in estimating the density of a population with Poisson scattering: Corvallis, OR, Oregon State University, Department of Statistics, Technical Report 60, 34 p.

Ramsey, F.L., and Scott, J.M., 1979, Estimating population densities from variable circular plot surveys, *in* Cormack, R.M., Patil, G.P., and Robson, D.S., eds., Sampling biological populations: Fairland, MD, International Cooperative Publishing House, p. 155–181.

Ramsey, F.L., and Scott, J.M., 1981, Tests of hearing ability, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 341–345. [Also available at https://sora.unm.edu/node/49.]

Ramsey, F.L., Scott, J.M., and Clark, R.T., 1979, Statistical problems arising from surveys of rare and endangered forest birds, *in* Proceedings of the 42nd Session of the International Statistical Institute, v. 1: Manila, Republic of Philippines, p. 471-483.

Ramsey, F.L., Wildman, Valerie, and Engbring, John, 1987, Covariate adjustments in variable area wildlife surveys: Biometrics, v. 43, no. 1, p. 1–11. [Also available at http://www.jstor.org/stable/2531943.]

Reed, J.M., Elphick, C.S., Zuur, A.F., Ieno, E.N., and Smith, G.M., 2007, Time series analysis of Hawaiian waterbirds, *in* Zuur, A.F., Ineo, E.N., and Smith, G.M., eds., Analyzing ecological data: New York, Springer-Verlag, p. 615–632. [Also available at https://ase.tufts.edu/biology/labs/reed/documents/pub2007ReedAED.pdf.]

Reed, J.R., Sincock, J.L., and Hailman, J.P., 1985, Light attraction in endangered procellariiform birds—Reduction by shielding upward radiation: Auk, v. 102, no. 2, p. 377–383. [Also available at https://sora.unm.edu/node/24108.]

Restani, Marco, and Marzluff, J.M., 2002, Funding extinction? Biological needs and political realities in the allocation of resources to endangered species recovery—An existing priority system, which should guide the Fish and Wildlife Service in endangered species recovery, is ineffective, and current spending patterns decrease long-term viability of island species: BioScience, v. 52, no. 2, p. 169–177. [Also available at http://bioscience.oxfordjournals.org/content/52/2/169.full.pdf+html.]

Reynolds, M.H., and Snetsinger, T.J., 2002, The Hawai'i rare bird search 1994–1996, *in* Scott, J.M., Conant, Sheila, and Van Riper, Charles, III, eds., Evolution, ecology, conservation and management of Hawaiian birds—A vanishing avifauna: Studies in Avian Biology, no. 22, p. 133–143. [Also available at http://www.arlis.org/docs/vol1/46665903.pdf.]

Reynolds, M.H., Seavy, N.E., Vekasy, M.S., Klavitter, J.L., and Laniawe, L.P., 2008, Translocation and early post-release demography of endangered Laysan teal: Animal Conservation, v. 11, no. 2, p. 160–168. [Also available at http://dx.doi.org/10.1111/j.1469-1795.2008.00166.x.]

Reynolds, R.T., Scott, J.M., and Nussbaum, R.A., 1980, A variable circular plot method for estimating bird numbers: Condor, v. 82, no. 3, p. 309–313. [Also available at https://sora.unm.edu/node/103083.]

Rodrigues, A.S.L., Akçakaya, H.R., Andelman, S.J., Bakarr, M.I., Boitani, Luigi, Brooks, T.M., Chanson, J.S., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, Michael, Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, Jan, Sechrest, Wes, Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., and Yan, Xie, 2004a, Global gap analysis—Priority regions for expanding the global protected areas network: BioScience, v. 54, no. 12, p. 1092–1100. [Also available at http://www.jstor.org/stable/10.1641/0006-3568(2004)054[1092:ggaprf]2.0.co;2.]

Rodrigues, A.S.L., Andelman, S.J., Bakarr, M.I., Boitani, Luigi, Brooks, T.M., Cowling, R.M., Fishpool, L.D.C., da Fonseca, G.A.B., Gaston, K.J., Hoffmann, Michael, Long, J.S., Marquet, P.A., Pilgrim, J.D., Pressey, R.L., Schipper, Jan, Sechrest, Wes, Stuart, S.N., Underhill, L.G., Waller, R.W., Watts, M.E.J., and Yan, Xie, 2004b, Effectiveness of the global protected area network in representing species diversity: Nature, v. 428, p. 640–643. [Also available at http://dx.doi.org/10.1038/nature02422.]

Schwartz, C.W., and Schwartz, E.R., 1949, A reconnaissance of the game birds of Hawaii: Hilo, HI, Board of Commissioners of Agriculture and Forestry, 168 p.

Scott, J.M., Baker, J.K., Berger, A.J., Kosaka, E., Landgraf, L., Ralph, C.J., Woodside, D., Bachman, R., and Burr, T., 1984, Hawaii forest bird recovery plan: Portland, OR, U.S. Fish and Wildlife Service, 72 p.

Scott, J.M., Conant, Sheila, and Pratt, H.D., 1979, Field identification of the Hawaiian creeper on the island of Hawaii: Western Birds, v. 10, no. 2, p. 71–80. [Also available at https://sora.unm.edu/node/122081.]

Scott, J.M., Conant, Sheila, and Van Riper, Charles, III, eds., 2002, Evolution, ecology, conservation and management of Hawaiian birds—A vanishing avifauna: Studies in Avian Biology, no. 22, 428 p. [Also available at https://sora.unm.edu/node/87.]

Scott, J.M., Csuti, Blair, Jacobi, J.D., and Estes, J.E., 1987a, Species richness—A geographic approach to protecting future biological diversity: BioScience, v. 37, no. 11, p. 782–788. [Also available at https://www.jstor.org/stable/1310544.]

Scott, J.M., Davis, Frank, Csuti, Blair, Noss, Reed, Butterfield, Bart, Groves, Craig, Anderson, Hal, Caicco, Steve, D'Erchia, Frank, Edwards, T,C., Jr., Ulliman, Joe, and Wright, R.G., 1993, Gap analysis—A geographic approach to protection of biological diversity: Wildlife Monographs, no. 123, 41 p. [Also available at http://www.jstor.org/stable/3830788.]

Scott, J.M., Goble, D.D., Wiens, J.A., Wilcove, D.S., Bean, Michael, and Male, Timothy, 2005, Recovery of imperiled species under the Endangered Species Act—The need for a new approach: Frontiers in Ecology and the Environment, v. 3, no. 7, p. 383–389. [Also available at http://www.jstor.org/stable/3868588.]

Scott, J.M., Jacobi, J.D., and Ramsey, F.L., 1981a, Avian surveys of large geographical areas—A systematic approach: Wildlife Society Bulletin, v. 9, no. 3, p. 190–200. [Also available at http://www.jstor.org/stable/3781837.]

Scott, J.M., and Kepler, C.B., 1983, Hawaii's upland forests: Science, v. 220, no. 4601, p. 1002. [Also available at http://www.jstor.org/stable/1690794.]

Scott, J.M., Kepler, C.B., Stine, P., Little, H., and Taketa, K., 1987b, Protecting endangered forest birds in Hawaii—The development of a conservation strategy: Transactions of the North American Wildlife and Natural Resources Conference, v. 52, p. 348–363.

Scott, J.M., Kepler, C.B., Van Riper, Charles, III, and Fefer, S.I., 1988, Conservation of Hawaii's vanishing avifauna—Hawaiian birds provide one of the best, and most spectacular, showcases of divergent evolution: BioScience, v. 38, no. 4, p. 238–252. [Also available at http://www.jstor.org/stable/1310847.]

Scott, J.M., Kepler, C.B., Van Riper III, Charles, Stone, C.P., and Fefer, S.I., 1989, Integrated conservation strategy for Hawaiian forest birds—A reply: BioScience, v. 39, no. 7, p. 476-479. [Also available at http://www.jstor.org/stable/1311141.]

Scott, J.M., Mountainspring, Stephen, Ramsey, F.L., and Kepler, C.B., 1986, Forest bird communities of the Hawaiian Islands—Their dynamics, ecology and conservation: Studies in Avian Biology, no. 9, 431 p. [Also available at https://sora.unm.edu/node/56.]

Scott, J.M., Mountainspring, Stephen, Van Riper, Charles, III, Kepler, C.B., Jacobi, J.D., Burr, T.A., and Giffin, J.G., 1984, Annual variation in the distribution, abundance and habitat response of the palila (*Loxioides balleiui*): Auk, v. 101, no. 4, p. 647–664. [Also available at https://sora.unm.edu/node/24018.]

Scott, J.M., and Ramsey, F.L., 1981a, Effects of abundant species on the ability of observers to make accurate counts of birds: Auk, v. 98, no. 3, p. 610–613. [Also available at https://sora.unm.edu/node/23582.]

Scott, J.M., and Ramsey, F.L., 1981b, Length of count period as a possible source of bias in estimating bird numbers, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 409–413. [Also available at https://sora.unm.edu/node/49.]

Scott, J.M., Ramsey, F.L., and Kepler, C.B., 1981b. Distance estimation as a variable in estimating bird numbers from vocalizations, *in* Ralph, C.J., and Scott, J.M., eds., Estimating numbers of terrestrial birds: Studies in Avian Biology, no. 6, p. 334–340. [Also available at https://sora.unm.edu/node/49.]

Scott, J.M., Ramsey, F.L., Lamertink, Martjan, Rosenberg, K.V., Rohrbaugh, Ron, Wiens, J.A., and Reed, J.M., 2008, When is an "extinct" species really extinct? Gauging the search efforts for Hawaiian forest birds and the ivory-billed woodpecker: Avian Conservation and Ecology, v. 3, no. 2, article 3 [n.p.], accessed September 9, 2016, at http://www.ace-eco.org/vol3/iss2/art3/.

Scott J.M., and Sincock, J.L., 1977, Recent observations on the birds of the Koolau Forest Reserve, Maui: Western Birds, v. 8, no. 3, p. 113–116. [Also available at https://sora.unm.edu/node/122019.]

Scott, J.M., Woodside, D.H., and Casey, T.L.C., 1977, Observations of birds in the Molokai Forest Reserve, July 1975: ‘Elepaio, v. 38, no. 3, p. 25–27.

Scowcroft, P.G., and Giffin, J.G., 1983, Feral herbivores suppress mamane and other browse species on Mauna Kea, Hawaii: Journal of Range Management, v. 36, no. 5, p. 638–645. [Also available at https://journals.uair.arizona.edu/index.php/jrm/issue/view/419.]

Shallenberger, R.J., 1977, An ornithological survey of Hawaiian wetlands: Honolulu, HI, Ahuimanu Productions, v. 1, 105 p.

Shallenberger, R.J., and Vaughn, G.K., 1978, Avifaunal survey in the central Koolau range, Oahu: Kailua, HI, Ahuimanu Productions, 51 p.

Simons, T.R., Kepler, C.B., Simons, P.M., and Kepler, A.K., 1985, Hawaii's seabird islands, no. 2—Hulu Island and vicinity, Maui: ‘Elepaio, v. 45, no. 11, p. 111–113.

Sincock, J.L., Daehler, R.E., Telfer, T., and Woodside, D.H., 1984, Kauai Forest Bird Recovery Plan: Portland, OR, U.S. Fish and Wildlife Service, p. 1–69.

Sincock, J.L., and Scott, J.M., 1980, Cavity nesting of the akepa on the island of Hawaii: Wilson Bulletin, v. 92, no. 2, p. 261–263. [Also available at https://sora.unm.edu/node/129739.]

Sincock, J.L., and Swedberg, G.E., 1969, Rediscovery of the nesting grounds of Newell's Manx shearwater (*Puffinus puffinus newelli*), with initial observations: Condor, v. 71, no. 1, p. 69–71. [Also available at https://sora.unm.edu/node/101817.]

Stone, C.P., 1985, Alien animals in Hawai'i's native ecosystems—Toward controlling the adverse effects of introduced vertebrates, *in* Stone, C.P., and Scott, J.M., eds., Hawai'i's terrestrial ecosystems—Preservation and management: Honolulu, HI, University of Hawaii, p. 251–297. [Also available at http://www.hear.org/books/hte1985/pdfs/hte1985.pdf.]

Stone, C.P., and Scott, J.M., eds., 1985, Hawai'i's terrestrial ecosystems—Preservation and management: Honolulu, HI, University of Hawaii, 584 p.

Stone, C.P., and Stone, D.B., eds., 1988, Conservation biology in Hawaii: Honolulu, HI, University of Hawaii, 252 p. [Also available at http://manoa.hawaii.edu/hpicesu/book/1988_chap/.]

Sugihara, R.T., 1997, Abundance and diets of rats in two native Hawaiian forests: Pacific Science, v. 51, no. 2, p. 189–198. [Also available at https://scholarspace.manoa.hawaii.edu/bitstream/10125/3110/1/v51n2-189-198.pdf.]

Swedberg, G.E., 1967, The koloa—A preliminary report on the life history and status of the Hawaiian duck (*Anas wyvilliana*): Honolulu, HI, Hawaii Department of Land and Natural Resources, 56 p.

Sykes, P.W., Kepler, A.K., Kepler, C.B., and Scott, J.M., 2000, Kauai oo (*Moho bracattus*), Oahu oo (*Moho apicalis*), Bishop's oo (*Moho bishop*), Hawaii oo (*Moho nobilis*), and kioea (*Chaetoptila angustipluma*), *in* Poole, A., and Gill, F., eds., The birds of North America, no 535: Philadelphia, PA, Birds of North America, Inc., 32 p. [Also available at http://bna.birds.cornell.edu/bna/species/535a/articles/introduction.]

Telfer, T.C., Sincock, J.L., Byrd, G.V., and. Reed, J.R., 1987, Attraction of Hawaiian seabirds to lights—Conservation efforts and effects of moon phase: Wildlife Society Bulletin, v. 15, no. 3, p. 406–413. [Also available at http://www.jstor.org/stable/3782548.]

The Nature Conservancy, 1982, The Endangered Hawaiian Forest Bird Project: Honolulu, HI, 21 p.

The Nature Conservancy, 1983, The Endangered Hawaiian Forest Bird Project: Honolulu, HI, 18 p.

The Nature Conservancy, 1985, The Endangered Hawaiian Forest Bird Project: Honolulu, HI, 12 p.

U.S. Department of Interior, 1964, Rare and endangered fish and wildlife of the United States: Washington D.C., U.S. Department of Interior, 62 p.

U.S. Fish and Wildlife Service, 1976a, Recovery effort intensifies to save Hawaii's endangered wildlife: Endangered Species Technical Bulletin, v. 1, no. 5, insert following p. 2.

U.S. Fish and Wildlife Service, 1976b, Hawaii bird survey yields mixed results: Endangered Species Technical Bulletin, v. 1, no. 5, p. 1–2.

U.S. Fish and Wildlife Service, 1977, Special report—Patuxent's endangered wildlife research program: Endangered Species Technical Bulletin, v. 2, no. 11, p. 6–9.

U.S. Fish and Wildlife Service, 1996, Endangered species expenditures—Fiscal year 1996: accessed December 2, 2014, at http://www.fws.gov/endangered/esa-library/pdf/FY_1996.pdf.

U.S. Fish and Wildlife Service, 2014, Nihoa Millerbird Translocation Project: accessed October 2, 2014, at http://www.fws.gov/pacificislands/nihoamillerbird.html.

Van Riper, Charles, III, and Scott, J.M., 1979, Observations on distribution, diet, and breeding of the Hawaiian thrush: Condor, v. 81, no. 1, p. 65–71. [Also available at https://sora.unm.edu/node/102920.]

Van Riper, Charles, III, Scott, J.M., and Woodside, D.M., 1978, Distribution and abundance patterns of the palila on Mauna Kea, Hawaii: Auk, v. 95, no. 3, p. 518–527. [Also available at https://sora.unm.edu/node/23172.]

Warner, R.E., 1960, A forest dies on Mauna Kea—How feral sheep are destroying an Hawaiian woodland: Pacific Discovery, v. 13, no. 2, p. 6–14.

Warner, R.E., ed., 1968, Scientific report of the Kipahulu Valley Expedition, Maui, Hawaii, 2 August–31 August, 1967: Honolulu, HI, The Nature Conservancy, 184 p. [Also available at http://manoa.hawaii.edu/hpicesu/speci/1967b.pdf.]

Warner, R.E., 1968, The role of introduced diseases in the extinction of the endemic Hawaiian avifauna: Condor, v. 70, no. 2, p. 101–120. [Also available at https://sora.unm.edu/node/101729.]

Warshauer, F.R., and Jacobi, J.D., 1982, Distribution and status of *Vicia menziesii* Spreng. (Leguminosae)—Hawai'i's first officially listed endangered plant species: Biological Conservation, v. 23, no. 2, p. 111–126. [Also available at http://dx.doi.org/10.1016/0006-3207(82)90034-9.]

Warshauer, F.R., Jacobi, J.D., LaRosa, A.M., Scott, J.M., and Smith, C.W., 1983, Technical report 48—The distribution, impact and potential management of the introduced vine *Passiflora mollisima* (Passifloraceae) in Hawai'i: Honolulu, HI, University of Hawaii, 39 p. [Also available at https://scholarspace.manoa.hawaii.edu/handle/10125/4329.]

Wilcove, D.S., and McMillan, Margret, 2006, The class of 67, *in* Goble, D.D., Scott, J.M., and Davis, F.W., eds., The Endangered Species Act at thirty—Reviewing the conservation promise: Covelo, CA, Island Press, p. 45–50.

Woodworth, B.L., Lieberman, A.A., Nelson, J.T., and Fretz, J.S., 2009, Puai'ohi. *in* Pratt, T.K., Atkinson, C., Banko, P.C., Jacobi, J.D., and Woodworth, B.L., eds., Conservation biology of Hawaiian forest birds—Implications for island avifauna: New Haven, CT, Yale University Press, p. 499–512.

Patuxent's Long-Term Research on Wolves

L. David Mech

The gray wolf (*Canis lupus*) was one of the first species placed on the Endangered Species List in 1967. The Endangered Species Act of 1973 legally protected the wolf along with other listed species.

Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, began its Endangered Wildlife Program in 1966, and U.S. Fish and Wildlife Service (USFWS) biologist Ray Erickson was assigned to lead it. In 1973, I was transferred to the program from Region 3 of the USFWS, having been employed there since 1969 to study wolves in Minnesota.

Endangered Species Act protection of the wolf fostered its quick population response, and wolf numbers began to increase in their reservoir in northeastern Minnesota and adjacent Canada and expand throughout northern Minnesota and eventually into Wisconsin and Michigan. In 2009, the number of wolves in Minnesota was approximately 3,000, and there were at least 1,500 in Wisconsin and Michigan.

This chapter describes Patuxent's wolf research, which continued into 1993 when Congress incorporated the USFWS's Endangered Wildlife Research Program into the National Biological Survey (NBS). Eventually the NBS merged with the U.S. Geological Survey, and the long-term wolf research program was transferred to the Northern Prairie Wildlife Research Center. Through all the administrative changes, Patuxent's wolf research project continued through the various agencies into the present (2016).

The text that follows is modified from Mech (2009).

The seeds for the blossoming of the wolf (*Canis lupus*) population throughout the upper Midwest were embodied in a long line of wolves that had persisted in the central part of the Superior National Forest (SNF) of northeastern Minnesota, probably since the retreat of the last glaciers more than 10,000 years ago. This line of wolves had withstood not only the various natural environmental factors that had shaped them through their evolution, but also logging, fires, market hunting of prey animals, bounties, aerial hunting, and poisoning. These factors had exterminated their ancestors and dispersed their offspring to only a few wolf pack territories in the more accessible areas. The dense and extensive stretch of wild land that is now known as the Boundary Waters Canoe Area Wilderness had proven too formidable a barrier even for the foes of the wolf, which had striven to eliminate the animal and had succeeded everywhere else in the contiguous United States. The wolves of the SNF became the reservoir for the recolonization of wolves throughout Minnesota and into neighboring Wisconsin and the Upper Peninsula of Michigan.

The only other part of the 48 contiguous United States where wolves still survived in the late 1960s was Isle Royale in Lake Superior, just 32 kilometers (km) (20 miles [mi]) from Minnesota's coast (Vucetich and Peterson, 2009). Those wolves had crossed Lake Superior's rare ice bridge to the 540-square-kilometer (km^2) (208-square-mile [mi^2]) island from Ontario (or possibly Minnesota) in 1949. At that time, Isle Royale was a national park, and the wolves that reached the island were fully protected there from bounties, poisons, and aerial hunting.

Dave Mech, U.S. Fish and Wildlife Service, drugging wild wolf in Minnesota to radiocollar it, early 1970s. Photo by Don Elsing, U.S. Forest Service.

U.S. Fish and Wildlife Service wildlife technicians radiocollaring a wolf in Minnesota, mid-1980s. Photo by U.S. Fish and Wildlife Service.

The wolves of the central SNF also were those that wildlife biologist, wilderness enthusiast, and writer Sigurd Olson (1938) had trailed in the snow in the late 1930s and that Milt Stenlund (1955) had studied later. Although neither worker realized it, molecular geneticists would eventually debate whether the wolves they studied were a blend of animals descended from the most recent colonization of North America across the Bering land bridge (*Canis lupus*), such as those in northwestern Canada and Alaska, and wolves that putatively evolved in North America (*Canis lycaon*), such as those that inhabit southeastern Ontario (Wilson and others, 2000). Wolves with both types of genetic markers sometimes live in the same pack, and apparently many wolves in Minnesota are hybrids between the two types (Mech and Federoff, 2002; Wilson and others, 2009).

When the last remaining 700 or so wolves inhabiting Minnesota, most of them in the SNF, were placed on the Federal Endangered Species List in 1967, it was only logical to begin studying them. A few groundbreaking studies had provided some insights into the biology of wolves (for example, Olson, 1938; Murie, 1944; Cowan, 1947; Stenlund, 1955; Mech, 1966; Pimlott and others, 1969); however, because wolves were so scarce in the contiguous United States and lived in low densities and inaccessible areas where they did survive, much basic information about wolves was unknown. Fortunately, when wolves were declared endangered, wildlife researchers were beginning to apply the revolutionary technology of radiotracking (Cochran and Lord, 1963). Kolenosky and Johnston (1967) had proved in Ontario that radiotracking wolves was practical. This technique promised to greatly enhance the ability of researchers to discover many new things about the behavior and ecology of wolves.

In 1968, I began a pilot project in the central SNF using radiotracking to determine whether wolf packs were territorial (Mech and Frenzel, 1971). My preliminary aerial observations during 1966–67 and 1967–68 had shown that several packs of different sizes and color combinations were present in the area. Without reliable identifiers for each pack, however, and without being able to find packs systematically, I had only a subjective notion that they were territorial. Therefore, radiotracking wolves from aircraft, which allowed both identifying individuals and systematically locating them, was the ideal method to answer this question.

Study Area

My study area encompassed about 2,060 km^2 (795 mi^2) immediately east of Ely in the east-central SNF (48° N.

Aerial radiotracking of wolves in Minnesota by U.S. Fish and Wildlife staff, mid-1980s. Photo by U.S. Fish and Wildlife Service.

Aerial observation of radiocollared wolves in Minnesota as part of the ongoing U.S. Fish and Wildlife Service wolf census, mid-1980s. Photo by U.S. Fish and Wildlife Service.

92° W.). Although somewhat smaller than the areas I have reported on earlier, this area encompassed the core of that region in which I have been able to monitor the wolf population during the entire 40-year study (1966–2006) (fig. 1). The area represents only a small percentage of the total range of wolves in Minnesota.

Topography in the study area varies from large stretches of swamps and uneven upland to rocky ridges, with altitudes ranging from about 325 to 700 meters (m) (1,066–2,297 feet [ft]) above the National Geodetic Vertical Datum of 1988. Winter temperatures below -35 degrees Celsius (°C) (-31 degrees Fahrenheit [°F]) are not unusual, and snow depths (from about mid-November through about mid-April) generally range from 50 to 75 centimeters (cm) (20–30 inches [in.]). Summer temperatures rarely exceed 35 °C (95 °F). Conifers, including jack pine (*Pinus banksiana*), white pine (*P. strobus*), red pine (*P. resinosa*), black spruce (*Picea mariana*), white spruce (*P. glauca*), balsam fir (*Abies balsamea*), white cedar (*Thuja occidentalis*), and tamarack (*Larix laricina*), predominate in the forest overstory. As a result of extensive cutting and fires, however, much of the coniferous cover is interspersed with large stands of white birch (*Betula papyrifera*) and aspen (*Populus tremuloides*). Heinselman (1993) presents a detailed description of the forest vegetation.

In the northeastern half of this area, as well as immediately north and east of it, the overwintering population of white-tailed deer (*Odocoileus virginianus*) was extirpated by about 1975 by a combination of severe winters, maturing vegetation, and a large wolf population (Mech and Karns, 1977), and the area has remained devoid of wintering deer ever since (Nelson and Mech, 2006). Moose (*Alces alces*) inhabit the entire area but occur at a higher density in the northeastern half. In spring, about a third of the deer inhabiting the southwestern half of the study area migrate into the northeastern half or beyond and return in fall (Hoskinson and Mech, 1976; Nelson and Mech, 1981). American beavers (*Castor canadensis*) occur throughout the study area, but generally are available as prey only from about April through November. Although all three prey species are consumed by wolves in the region (van Ballenberghe and others, 1975), the primary prey of wolves inhabiting the northeastern part has been moose since about 1975, whereas wolves in the southwestern part have consumed primarily deer.

Year-round hunting and trapping of wolves were legal until October 1970, when wolves were fully protected on Federal land within the SNF by the U.S. Forest Service. In August 1974, wolves were protected under the Endangered Species Act of 1973. In 1978, wolves in Minnesota were reclassified as threatened, but remained legally protected except for depredation control outside the SNF (Fritts and others, 1992). Illegal taking of wolves continued, however—primarily in fall and winter (Mech, 1977b; Mech and Hertel, 1983). Wolves in the upper Midwest, including Minnesota, were removed from the Endangered Species List in March 2007.

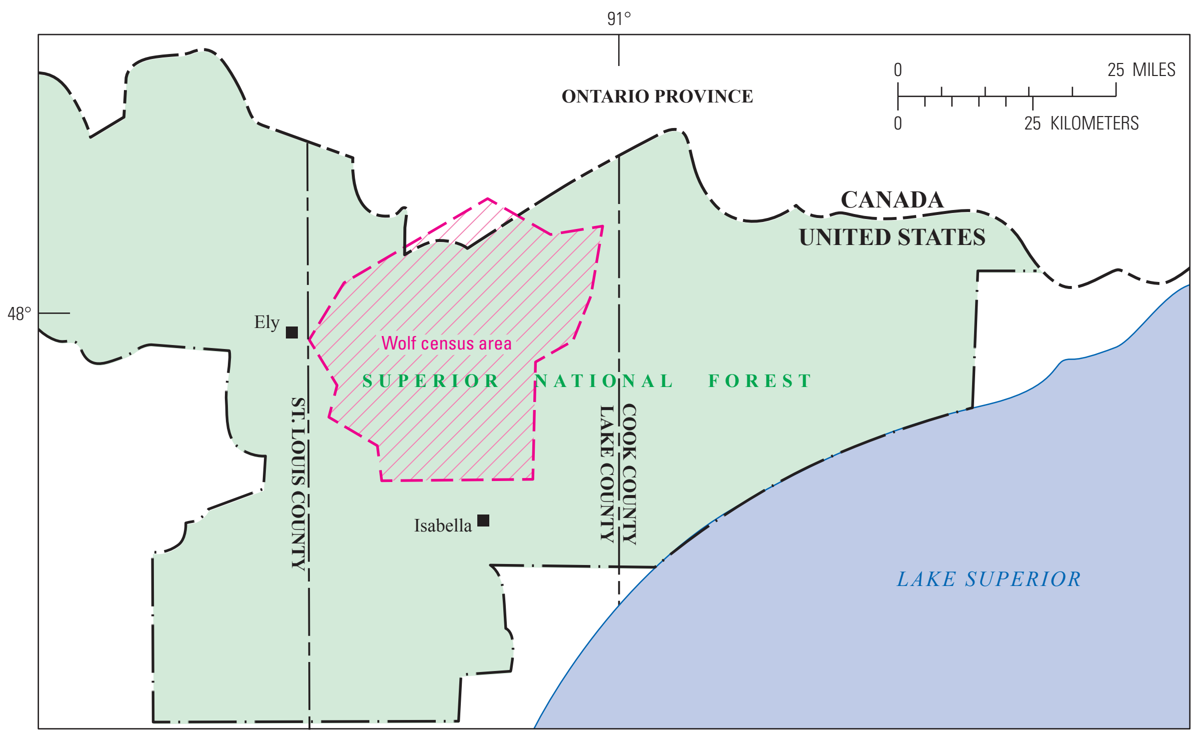

Figure 1. Location of the central Superior National Forest study area, Minnesota. (Modified from Mech, 2009)

Long-Term Research on Wolves, Wolf Packs, and Population Trends

My main objective at the beginning of the study was to determine spacing in the wolf population, but I also realized that by being able to find and identify each marked pack, I could obtain much additional information. For example, during winter I could count pack members, determine how consistently each pack maintained its size, track its movements, find and examine its kills, and locate marked wolves after death. In addition, if the packs were territorial, radiotagging a sufficient number of packs in the study area would allow me to determine the total number of wolves there by locating each pack and counting the pack members.

Over the long term, monitoring the population trajectory of wolves in the SNF became my primary objective. The longer this study continued, the more valuable the data on changes in population size became. The only other data available on wolf population trends were those from the Isle Royale study, which began in 1959 (Mech, 1966) and was continued by other researchers (Vucetich and Peterson, 2009). Although those data are of great interest, they characterize an island with no emigration or immigration and therefore cannot fully represent most populations of wolves. The opportunity to gather long-term data on a population of mainland wolves and determine the factors that drove the changes in that population was highly attractive.

The primary technique used has been live-trapping wolves in modified steel foot-traps, anesthetizing each animal (except most pups), weighing them, sampling their blood, and outfitting them with a radiocollar (Mech, 1974). Since 2000, my assistants, students, associates, and I also have estimated the age of each wolf on the basis of tooth wear (Gipson and others, 2000). We aerially radiotracked the wolves at least weekly during most years, and observed and counted them as often as possible, primarily from December through March (Mech, 1973, 1986). The largest number of wolves we saw during winter in each pack was considered to be the pack size. If the territory of a radiocollared pack fell partly outside the census area, the number of wolves assigned to the census area was multiplied by the percentage of the territory that fell in the area.

Territoriality of Wolf Packs

Each time we located a wolf, we recorded its location. We plotted these locations from October 1 through March 30 and from April 1 through September 30 each year, and used minimum convex polygons (MCPs) (Mohr, 1947) to represent territories (Mech, 1973, 1977b, 1986).

Pack territories based on radio locations were delineated for each radiocollared pack in the study area each year; however, some packs died out, new ones formed, and not all packs were radiocollared each year. The existence of nonradiocollared packs in the study area in any year was inferred from voids in the maps of the territorial mosaic. Incidental observations of nonradiocollared packs and (or) their tracks in these voids indicated the sizes of these packs. (Some data pertaining to individual packs in some years in this chapter may differ from data presented previously [Mech, 1973, 1977c, 1986] as a result of a reinterpretation of the data on the basis of additional experience with these packs.) If data on individual packs were unavailable for any year, pack-size estimates were made on the basis of the previous and subsequent years' data for packs occupying those territories. Because an unknown portion of the territories of some of these packs may have fallen outside the census area, these data are not precise. Data collected in 1966–67 and 1967–68 were based solely on observations of nonradiocollared packs during intensive aerial observations. In the estimates of population trajectory for wolves presented here, I considered the number of lone wolves to be inconsequential because they represented only a small proportion of the population, and most of these individuals were dispersers accounted for by using the maximum numbers in each pack. During the earlier part of the study, lone wolves were estimated to constitute 7 to 14 percent of the population (Mech, 1973).

U.S. Fish and Wildlife Service staff examining wolf-killed deer, Minnesota, mid-1980s. Photo by U.S. Fish and Wildlife Service.

Because monitoring the population density of wolves in the study area required the maintenance of radiocollars on several adjacent packs, the project became a data-gathering system that allowed several parallel studies. Knowing where wolf packs lived regularly and how many members each contained allowed Fred Harrington and me to approach on foot and howl to them under various conditions to determine their responses (Harrington and Mech, 1979). By tracking known packs in the snow and examining their scent marks, Roger Peters and I could describe and quantify scent-marking behaviors (Peters and Mech, 1975). Russell Rothman and I conducted a similar study on newly formed pairs of wolves (Rothman and Mech, 1979).

From 1968 through 2006, we live-trapped 712 wolves (119 female pups, 141 male pups, 239 females ≥1 year old, and 213 males ≥1 year old) in the study area, for a total of 1,044 captures of wolves from 15 or more packs. The number of packs radiocollared each year varied, and over the 38 years of radiotracking, some packs disappeared and many new ones formed. Weights of both males and females peaked at 5 or 6 years of age, with mean peak weights of 40.8 kg (89.9 pounds [lbs]) ± a standard error (SE) of 1.5 kg (3.3 lbs) and 31.2 kg (68.8 lbs) ± a SE of 2.4 kg (5.3 lbs), respectively (Mech, 2006a). From 2000 to 2004, the age structure of the population was relatively young, with only 12 percent of animals more than 1 year old being more than 5 years old (Mech, 2006b). Some wolves, however, lived to be 13 years old (Mech, 1988). Most females 4 to 9 years of age had bred, as determined by assessing nipple sizes; those that had not bred had lower average weights than those that had.

The study clearly established for the first time that each radiocollared pack inhabited a separate territory (Mech, 1973). Pimlott and others (1969, p. 78) had concluded that "the results are far from conclusive on the question of whether or not pack territoriality is involved," and Mech (1970, p. 105) had speculated that wolf packs might even have "spatio-temporal" territories. Radiotracking wolves in the SNF showed that they are territorial and that their territories are spatial (Mech, 1973). The wolves advertised and defended their territories by howling (Harrington and Mech, 1979), scent-marking (Peters and Mech, 1975), and direct aggression (Mech, 1994).

Analysis of wolf-pack territory size was not in the scope of this study. On the basis of MCPs of radiocollared wolf packs, territory sizes varied from 125 to 310 km² (48–120 mi²) through winter 1973 (Mech, 1974). During 1997–99, however, the Farm Lake pack inhabited only 23 to 33 km² (9–13 mi²), a density of 182 to 308 wolves per 1,000 km² (472–798 per 1,000 mi²), the highest density ever reported (Mech and Tracy, 2004). The overall territorial structure gradually shifted over the years, although some semblance of the early structure was still apparent in 2006–07 (fig. 2).

Maximum winter pack sizes during 233 radiocollared pack-years (1 pack radiotracked for 1 year = 1 pack-year) varied from 2 to 15 and averaged 5.6 ± 0.20 (SE). Maximum winter pack sizes for 11 packs with at least 11 years of data varied from 2 to 8 to 2 to 15 per year, with means of 3.7 ± 0.5 (SE) to 7.9 ± 1.1 (SE); the small standard errors around these means show that individual packs in the study area tended to retain their basic sizes. Approximately 67 percent of the packs included a maximum of two to six members during winter, and 90 percent included two to nine (fig. 3).

One of the more novel findings of our long-term study was the concept of the buffer zone between wolf-pack territories (Mech, 1977c). There appears to be an area of 1 to 2 km (0.6–1.3 mi) around the edge of a wolf-pack territory where neighboring packs travel but spend little time (Mech and Harper, 2002), and wolves fight there, commonly to the death, if an encounter between packs occurs (Mech, 1994). Therefore, prey seem to survive longer in these zones. When the deer population declined early in the study, most of those

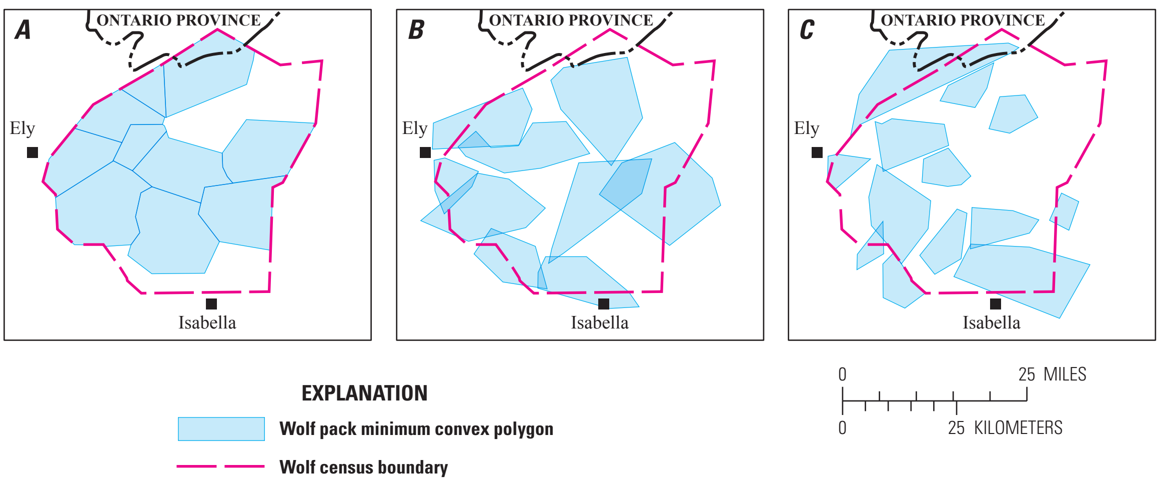

Figure 2. Territorial structure of wolf packs in the central Superior National Forest study area, Minnesota. *A*, represents the territorial structure from 1971 to 1973, but arbitrarily extends each pack's minimum convex polygon (MCP) to the boundaries of its neighbors (Mech, 1973). *B*, represents the actual MCPs for radiocollared packs during winter 1984–85 (Mech, 1986). *C*, represents the same for 2006–07. In 1984–85, a nonradiocollared wolf pack consisting of an estimated six wolves occupied an unknown part of the northeastern area, and in 2006–07, a nonradiocollared pack of eight wolves occupied the northeastern area. Several aerial surveys over the east-central area indicated that no wolves were present during winter 2006–07. (Modified from Mech, 2009)

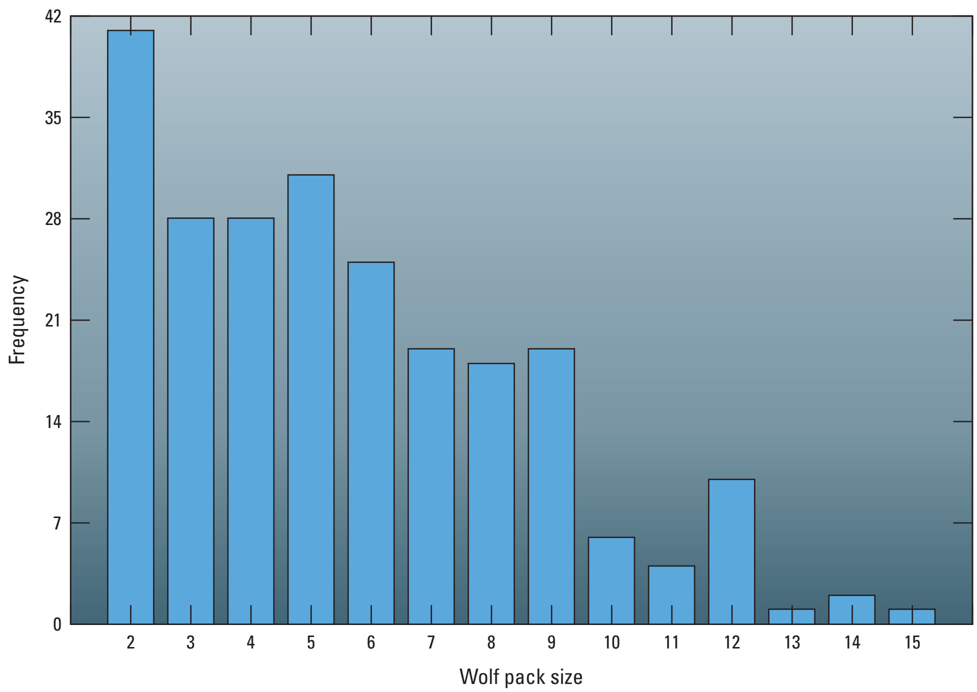

Figure 3. Distribution of maximum winter pack sizes in the central Superior National Forest study area, Minnesota, winter 1966–67 through winter 2006–07. (Modified from Mech, 2009)

remaining inhabited these zones (Hoskinson and Mech, 1976; Mech, 1977a, c; Nelson and Mech, 1981). Even after the deer population increased, we continued to find evidence of this relation (Kunkel and Mech, 1994).

Buffer zones between territories of wolf packs are important to territorial maintenance. In addition to fighting, adjacent packs scent-mark disproportionately there (Peters and Mech, 1975). Howling in and near the buffer zone undoubtedly also is important. Harrington and Mech (1979, p. 243) estimated that each pack on average is within howling range of at least one neighboring pack about 78 percent of the time, and "the probability of one pack hearing another, and the probability of encounters both increase when packs approach one another at a common border."

Population Trends

In our 2,060-km^2 (795-mi^2) study area, numbers of wolves ranged from 35 to 87 with a mean of 59 and a median of 55, and a density of 17 to 42 wolves per 1,000 km^2 (44–109 per 1,000 mi^2) with a mean of 28 per 1,000 km^2 (73 per 1,000 mi^2) and median of 27 per 1,000 km^2 (70 per 1,000 mi^2). The population decreased between the winters of 1968–69 and 1973–74 and subsequently increased ($r^2 = 0.33$; $P < 0.001$) (fig. 4). Mean pack size also increased after winter 1973–74 ($r^2 = 0.21$; $P < 0.01$). In winter 2006–07, the population was estimated to be 81 wolves, or 39 wolves per 1,000 km^2 (101 per 1,000 mi^2). Both the population and average-pack-size trends increased after 1973–74 at a mean annual rate of 0.01. Annual changes in the estimated size of the wolf population were related to annual changes in mean sizes of radiocollared packs ($r^2 = 0.35$; $P < 0.001$). Estimates of pack-size and population change were accurate because radiocollared packs were easily located and counted several times each winter.

From the beginning of the study through about the late 1980s, the proportion of wolves on a deer economy in our area decreased, and more wolves had to rely on moose. The decline in wolves through 1982 coincided with the decline in deer (fig. 5), which in turn coincided with maximum cumulative 3-year snow depth (Mech and others, 1987a). When the snowfall moderated in 1982–83, the number of deer began increasing again (Fuller and others, 2003). The trend for the wolf population that depended on deer declined curvilinearly, reaching a minimum about 1991 and gradually increasing through 2007 ($r^2 = 0.86$; $P < 0.00001$). The wolf population in the northern, northeastern, and eastern parts of the area that preyed increasingly on moose showed a reverse-sigmoid increase ($r^2 = 0.80$) from about 1978 through 2007, related ($r^2 = 0.12$; $P = 0.06$) to an increase in abundance of moose from 3,900 individuals in 1978 to 6,460 in 2007 (Mark Lennarz, Minnesota Department of Natural Resources, written commun., 2006).

Canine parvovirus (CPV) began affecting the SNF wolf population in the early 1980s and had its greatest effect

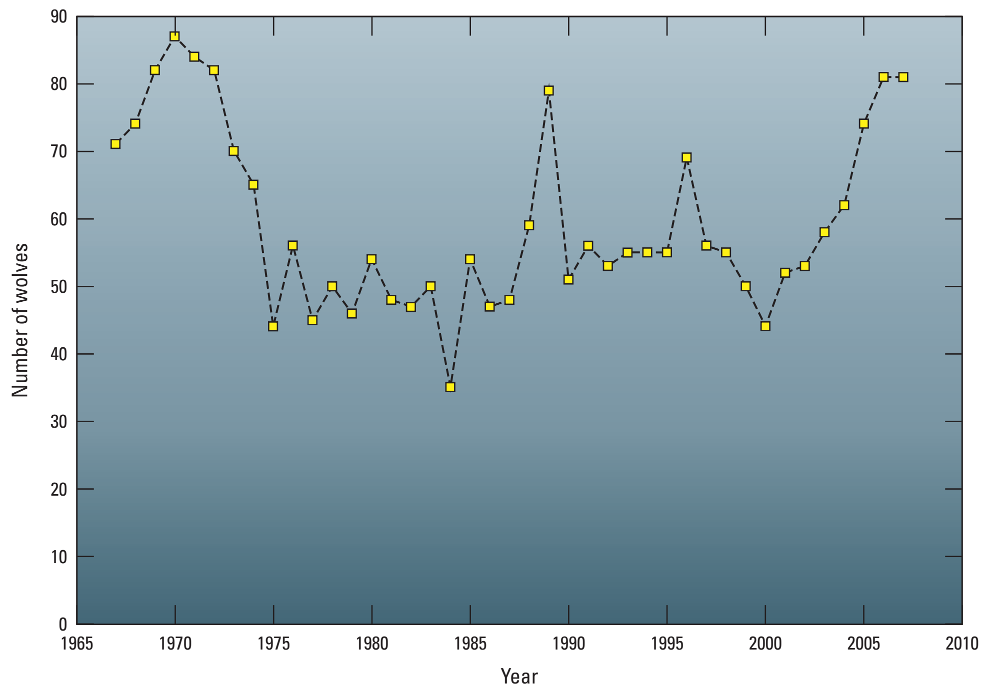

Figure 4. Size of the wolf population in the central Superior National Forest, MN, 1967–2007. (Modified from Mech, 2009)

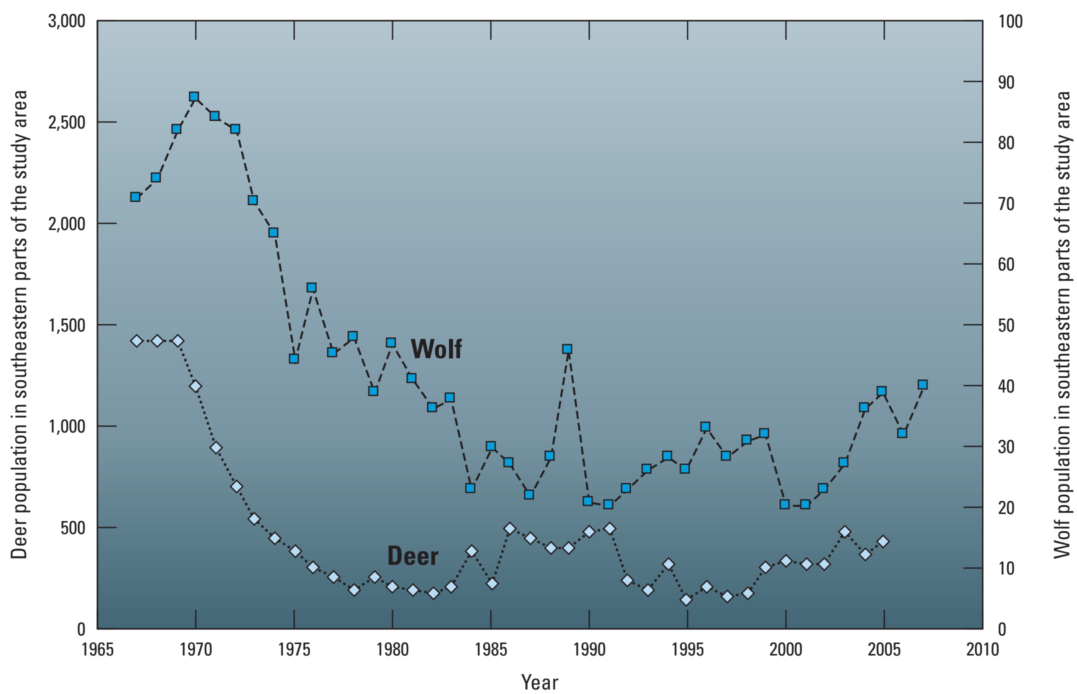

Figure 5. Size of the deer (1967–2005) and wolf (1967–2007) populations in southeastern parts of the central Superior National Forest study area, Minnesota. (Modified from Fuller and others, 2003, fig. 6.6)

from 1987 to 1993, after which the wolf population gained resistance (Mech and Goyal, 2011). From 1987 to 1993, the annual change in the wolf population was negatively related to seroprevalence of CPV (r = -0.92; P = < 0.01). The relation between CPV seroprevalence and an index of survival of wolf pups was r =- 0.73 (P = 0.06) (Mech and Goyal, 2011).

Dispersal

The wolf population occurred at a high density, and packs occupied most of the available space. Any excess production of pups therefore resulted in their dispersal as 1- to 3-year-olds (Mech, 1987; Gese and Mech, 1991). Some dispersers became nomadic in the general vicinity of their natal population, covering as much as 4,100 km^2 (1,577 mi^2) (Mech and Frenzel, 1971; Mech, 1987). Others, however, dispersed farther and helped recolonize other parts of Minnesota, as well as Wisconsin and Michigan (Mech and others, 1995; Merrill and Mech, 2000).

Studies of Deer Ecology

As I radiotracked wolves, it became clear that a thorough study of wolf ecology would require examination of the natural history and ecology of their main prey, white-tailed deer. In 1973, I began radiotagging deer in the same area and traced their movements, survival, and mortality along with those of the radiocollared wolves. Reed Hoskinson, University of Minnesota (Hoskinson and Mech, 1976), and then Mike Nelson, U.S. Fish and Wildlife Service (Nelson and Mech, 1981; Nelson, 1993), conducted the initial studies of deer. Mike remained with the project as a collaborator in charge of deer research (DelGiudice and others, 2009). Ted Floyd joined us as a graduate student and used our radiotagged deer to pioneer the technique of evaluating observability biases in aerial ungulate censuses, applying an adjustment for observability to our data (Floyd and others, 1979). We used this technique to count deer in winter through 1992 (Nelson and Mech, 1986a), until funding constraints forced us to discontinue it. Since 1992, we have used buck harvest in part of our area to index deer population trend. The number of deer in our area decreased from the late 1960s and 1970s, reached a minimum about 1981, and has slowly and intermittently increased since then (fig. 5).

From 1973 to 2007, we radiocollared 347 deer, mostly females. In addition to learning much basic natural history about these deer (for example, Hoskinson and Mech, 1976; Nelson and Mech, 1981, 1987, 1990; Nelson, 1993; Mech and McRoberts, 1990), we found that wolves rarely killed adult females during summer (Nelson and Mech, 1986c), that wolf predation was greatest when snow was deepest (Nelson and Mech, 1986b), that daily predation rates during fall migration were 16 to 107 times those of deer in wintering areas or yards (Nelson and Mech, 1991), that survival of adult females was related to the nutritional condition of their mothers, and that survival of yearlings to 2-year-olds was related to the nutritional condition of their grandmothers (Mech and others, 1991).

We learned that condition was an important factor predisposing deer to predation by wolves, and various measures of condition provided evidence. Wolves tended to kill old deer (Mech and Frenzel, 1971; Mech and Karns, 1977; Nelson and Mech, 1986a); deer with abnormalities (Mech and others, 1970; Mech and others, 1971; Mech and Karns, 1977); deer with low blood fat (Seal and others, 1978); deer with low marrow fat (Mech and Frenzel, 1971; Mech, 2007); and newborn fawns of below-average weight and (or) with low serum urea nitrogen (Kunkel and Mech, 1994).

Deer condition in winter depends on snow depth because the deeper the snow, the more difficult it is to find food (Verme, 1968). Therefore, we were not surprised to find that the size of, and trend in, deer populations were related to snow conditions (Mech and others, 1971; Mech and Karns, 1977; Mech and others, 1991; Mech and others, 1987a; McRoberts and others, 1995; but see Messier, 1995).

Follow-Up Studies from, and Adjuncts to, the Superior National Forest Wolf Research

While trapping wolves in the SNF, I quickly realized that if we could capture them more easily, we could examine them more often and better monitor their weight, blood values, and condition. Furthermore, the early collars we used commonly did not last even 1 year, so replacing them was important. The longer data were collected, the more complete a picture we could gain of the natural history of packs and the spatial organization of the population.

To determine whether radio signals could be used to remotely dart and recapture a radiocollared wolf, I consulted my former coworker, Bill Cochran (University of Minnesota), who had pioneered radiotracking (Cochran and Lord, 1963). Cochran suggested using a squib—an electrically detonated matchhead, like a tiny flashbulb. When a signal sends current through the squib, it flashes. Gunpowder in front of the squib detonates, drives a dart, and injects a drug. This technique, however, requires a radio receiver attached to the dart to pick up the signal, and an electrically detonated dart small enough to be attached to a wolf collar. The dart also has to be wolf- and waterproof, and in a position to inject a drug into a wolf. We designed the mechanism, but needed a talented machinist to produce the experimental prototypes. Lee Simmons, Director of the Henry Doorly Zoo in Topeka, KS, came to the rescue. Ulysses (Ulie) Seal of the U.S. Veterans Administration Hospital, Minneapolis, MN, and an expert on drugs suitable for use in such a collar (Seal and others, 1970), completed the development team.

The time between conception and availability of a working dart collar was about 10 years. Sometime during the final development, Rick Chapman, a graduate student on the project, was hired by 3M Company, which had sufficient interest in the concept of the collar to invest considerable time and funding to perfect it (Mech and others, 1984).

We also tested the capture collar on several deer (Mech and others, 1990) and used it to conduct studies of year-round nutritional condition in deer (DelGiudice and others, 1992) and of capture stress (DelGiudice and others, 1990). We then tested the collar successfully on wild wolves (Mech and Gese, 1992) and used it to obtain such elusive types of data as serial weights and blood values on the same wolf over long periods, as well as field metabolic rates (Nagy, 1994). The most important contribution of the capture collars, however, was unexpected. To facilitate recovery of the collar in case it failed, Chapman invented a remote-release mechanism. When that mechanism was applied to global positioning system (GPS) collars, then being developed, biologists could retrieve the GPS collars to download the data (Merrill and others, 1998). Unfortunately, because commercial companies found it much more lucrative to produce GPS collars than capture collars, the latter soon became unavailable.

Blood Sampling

During the 1970s, Ulie Seal began studying aspects of blood that had direct application to our studies. I then began a productive collaboration with him, collecting blood from both wolves and deer. Although my main objective was to determine the nutritional condition of my study animals (Seal and others, 1975; Seal and others, 1978), the samples gained more significance for their usefulness in determining seroprevalence of CPV in our wolves (Mech and Goyal, 2011).

Studies of Captive Wolves

As these projects produced new information, they also spawned many questions. Some could be answered with additional field studies, but others required a different approach. Therefore, Jane Packard (Texas A&M University), Ulie Seal, and I set up a colony of captive wolves that could be observed closely and examined frequently, blood-sampled, and otherwise studied intensively (Seal and others, 1987; Seal and Mech, 1983; Packard and others, 1983, 1985). As that project grew, Cheri Asa, St. Louis Zoo (Asa and others, 1985; 1990), James Raymer, University of Indiana (Raymer and others, 1985, 1986); and Terry Kreeger, University of Minnesota (Kreeger and others, 1990, 1997) became additional collaborators. Glenn DelGiudice (University of Minnesota Ph.D. student) made use of both the captive wolf colony (Mech and others, 1987b) and the field studies in the SNF (DelGiudice and others, 1988, 1989) to begin investigations of the nutritional condition of various animals by using analyses of urine in the snow.

Beyond the Superior National Forest

Several other spin-offs of research in the SNF increased our knowledge of wolves and wolf recovery in the Midwest and elsewhere. Because radiotracking was so productive in the SNF where the wolf population had been long established and occurred at high density, I wanted to use the same techniques to examine a recently colonized wolf population. For this I recruited Steve Fritts (USFWS) to study a recently established wolf population 290 km (181 mi) away in northwestern Minnesota (Fritts and Mech, 1981).

We also assisted the Minnesota Department of Natural Resources in starting a research project on wolves in north-central Minnesota similar to the SNF study. We taught colleagues, students, and technicians how to live-trap, anesthetize, radiotag, and radiotrack wolves. Many of them continued research on wolves in other areas (Berg and Kuehn, 1982; Fuller and others, 2003; Boyd and others, 1995; Meier and others, 1995; Burch and others, 2005; Ream and others, 1991). Furthermore, we conducted an experimental reintroduction of four wolves into northern Michigan that demonstrated that translocated wolves held for a week tended to return homeward (Weise and others, 1979).

Biologists in other areas became interested in doing similar studies, so I was invited to Italy; to Riding Mountain National Park, Canada; and to Alaska to help organize their first radiotracking studies of wolves (Boitani and Zimen, 1979; Carbyn, 1980; Peterson and others, 1984). Some of my technicians helped start projects in Portugal and Romania. Furthermore, the Patuxent wolf project hosted biologists from Sweden, Israel, Portugal, Poland, Spain, Croatia, India, Italy, Mexico, Norway, Turkey, and Austria to receive training in wolf research techniques in the SNF study area.

Wolf Depredation Control Program

Responses to complaints about livestock depredation had been managed by the Animal Damage Control Branch of the USFWS, but in 1978, when wolves in Minnesota were reclassified from endangered to threatened, I was asked to design a control program for wolves. This program had to stay within the directives of a court order while still attempting to reduce wolf depredations on livestock—that is, taking a minimal number of wolves, yet satisfying farmers and ranchers. I was appointed to direct the program, and I assigned Steve Fritts, with his newly minted Ph.D. degree, to run it. Bill Paul, a newly hired technician on the SNF project, was his main assistant. These two workers conducted a well-respected program that continues under the auspices of the U.S. Department of Agriculture Wildlife Services (Fritts and others, 1992).

We tried many alternative nonlethal methods to reduce losses of livestock, such as translocating depredating wolves (Fritts and others, 1985), and using "fladry" (flagging), blinking lights, guard dogs, and taste aversion (Fritts and others, 1992), and conceived several other methods such as radiocontrolled shock collars, radioactivated alarm systems, human-applied scent marking, and recorded howling. None proved to be very effective or practical because the law allowed lethal control and the population was not so low (1,250 in 1978) that every last member needed to be preserved at all costs. Some of these concepts have since proved useful where lethal control is allowed or where wolf numbers are so low that extraordinary means are justified (Shivik, 2006; Musiani and others, 2003; Schultz and others, 2005). Fritts eventually was promoted to assistant leader of the Endangered Species Wildlife Research Program at Patuxent under leader Randy Perry, who had assumed Erickson's position when he retired. Fritts later went on to head the USFWS's wolf reintroduction into Yellowstone National Park with Ed Bangs.

Future Directions

To understand the functioning of natural wolf populations, it is important to follow the long-term trend of at least one long-extant population. The value of the information that science has obtained from the Isle Royale wolf population over 50 years is immeasurable (Vucetich and Peterson, 2009); however, the fact that the population is restricted to an island with no regular immigration or emigration is problematic. Because the central SNF study is the longest running, non-island study of a wolf population, continuing this investigation as long as possible is critical. Patuxent deserves credit for supporting this important work during its first two and a half decades.

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References Cited

Asa, C.S., Mech, L.D., Seal, U.S., and Plotka, E.D., 1990, The influence of social and endocrine factors on urine-marking by captive wolves (*Canis lupus*): Hormones and Behavior, v. 24, no. 4, p. 497–509. [Also available at http://dx.doi.org/10.1016/0018-506X(90)90038-Y.]

Asa, C.S., Peterson, E.K., Seal, U.S., and Mech, L.D., 1985, Deposition of anal sac secretions by captive wolves (*Canis lupus*): Journal of Mammalogy, v. 66, no. 1, p. 89–93. [Also available at http://dx.doi.org/10.2307/1380960.]

Berg, W.E., and Kuehn, D.W., 1982, Ecology of wolves in north-central Minnesota, *in* Harrington, F.H., and Paquet, P.C., eds., Wolves of the world—Perspectives of behavior, ecology, and conservation: Park Ridge, NJ, Noyes Publications, p. 4–11.

Boitani, Luigi, and Zimen, Erik, 1979, The role of public opinion in wolf management, *in* Klinghammer, Erich, ed., The behavior and ecology of wolves: New York, Garland STPM Press, p. 471–477.

Boyd, D.K., Paquet, P.C., Donelon, Steve, Ream, R.R., Pletsher, D.H., and White, C.C., 1995, Transboundary movements of a colonizing wolf population in the Rocky Mountains, *in* Carbyn, L.N., Fritts, S.H., and Seip, D.R., Ecology and conservation of wolves in a changing world: Edmonton, Alberta, Canada, Canadian Circumpolar Institute, Occasional Publication 35, p. 135–140.

Burch, J.W., Adams, L.G., Follmann, E.H., and Rexstad, E.A., 2005, Evaluation of wolf density estimation from radiotelemetry data: Wildlife Society Bulletin, v. 33, no. 4, p. 1225–1236. [Also available at http://dx.doi.org/10.2193/0091-7648(2005)33[1225:EOWDEF]2.0.CO;2.]

Carbyn, L.N., 1980, Ecology and management of wolves in Riding Mountain National Park, Manitoba: Edmonton, Alberta, Canadian Wildlife Service, Final Report, L.M.S. Study Report No. 10, 182 p.

Cochran, W.W., and Lord, R.D., Jr., 1963, A radio-tracking system for wild animals: Journal of Wildlife Management, v. 27, no. 1, p. 9–24. [Also available at http://dx.doi.org/10.2307/3797775.]

Cowan, I.M., 1947, The timber wolf in the Rocky Mountain national parks of Canada: Canadian Journal of Research, v. 25d, no. 5, p. 139–174. [Also available at http://dx.doi.org/10.1139/cjr47d-012.]

DelGiudice, G.D., McCaffery, K.R., Beyer, D.E., Jr., and Nelson, M.E., 2009, Prey of wolves in the Great Lakes region, *in* Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., Recovery of gray wolves in the Great Lakes of the United States—An endangered species success story: New York, Springer Science+Business Media, p. 155–173. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1_10.]

DelGiudice, G.D., Mech, L.D., Kunkel, K.E., Gese, E.M., and Seal, U.S., 1992, Seasonal patterns of weight, hematology, and serum characteristics of free-ranging female white-tailed deer in Minnesota: Canadian Journal of Zoology, v. 70, no. 5, p. 974–983. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z92-139?journalCode=cjz#.WDjNuWe7qRs.]

DelGiudice, G.D., Mech, L.D., and Seal, U.S., 1988, Chemical analyses of deer bladder urine and urine collected from snow: Wildlife Society Bulletin, v. 16, no. 3, p. 324–326. [Also available at http://www.jstor.org/stable/3782111.]

DelGiudice, G.D., Mech, L.D., and Seal, U.S., 1989, Physiological assessment of deer populations by analysis of urine in the snow: Journal of Wildlife Management, v. 53, no. 2, p. 284–291. [Also available at http://dx.doi.org/10.2307/3801124.]

DelGiudice, G.D., Mech, L.D., and Seal, U.S., 1990, Effects of winter undernutrition on body composition and physiological profiles of white-tailed deer: Journal of Wildlife Management, v. 54, no. 4, p. 539–550. [Also available at http://dx.doi.org/10.2307/3809347.]

Floyd, T.J., Mech, L.D., and Nelson, M.E., 1979, An improved method of censusing deer in deciduous-coniferous forests: Journal of Wildlife Management, v. 43, no. 1, p. 258–261. [Also available at http://dx.doi.org/10.2307/3800668.]

Fritts, S.H., and Mech, L.D., 1981, Dynamics, movements, and feeding ecology of a newly protected wolf population in northwestern Minnesota: Wildlife Monographs No. 80, 79 p. [Also available at http://www.jstor.org/stable/3830611.]

Fritts, S.H., Paul, W.J., and Mech, L.D., 1985, Can relocated wolves survive?: Wildlife Society Bulletin, v. 13, no. 4, p. 459–463. [Also available at http://www.jstor.org/stable/3782671.]

Fritts, S.H., Paul, W.J., Mech, L.D, and Scott, D.P., 1992, Trends and management of wolf-livestock conflicts in Minnesota: U.S. Fish and Wildlife Service, Resource Publication 181, 27 p. [Abstract available at https://pubs.er.usgs.gov/publication/5230226.]

Fuller, T.K., Mech, L.D., and Fitts-Cochrane, Jean, 2003, Wolf population dynamics, *in* Mech, L.D., and Boitani, Luigi, eds., Wolves—Behavior, ecology, and conservation: Chicago, University of Chicago Press, p. 161–191.

Gese, E.M., and Mech, L.D., 1991, Dispersal of wolves (*Canis lupus*) in northeastern Minnesota, 1969–1989: Canadian Journal of Zoology, v. 69, no. 12, p. 2946–2955. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z91-415.]

Gipson, P.S., Ballard, W.B., Nowak, R.M., and Mech, L.D., 2000, Accuracy and precision of estimating age of gray wolves by tooth wear: Journal of Wildlife Management, v. 64, no. 3, p. 752–758. [Also available at http://dx.doi.org/10.2307/3802745.]

Harrington, F.H., and Mech, L.D., 1979, Wolf howling and its role in territory maintenance: Behaviour, v. 68, no. 3–4, p. 207–249. [Also available at http://www.jstor.org/stable/4533952.]

Heinselman, Miron, 1993, The Boundary Waters wilderness ecosystem: Minneapolis, MN, University of Minnesota Press, 336 p.

Hoskinson, R.L., and Mech, L.D., 1976, White-tailed deer migration and its role in wolf predation: Journal of Wildlife Management, v. 40, no. 3, p. 429–441. [Also available at http://dx.doi.org/10.2307/3799944.]

Kolenosky, G.B., and Johnston, D.H., 1967, Radio-tracking timber wolves in Ontario: American Zoologist, v. 7, no. 2, p. 289–303. [Also available at http://www.jstor.org/stable/3881433.]

Kreeger, T.J., DelGiudice, G.D., and Mech, L.D., 1997, Effects of fasting and refeeding on body composition of captive gray wolves (*Canis lupus*): Canadian Journal of Zoology, v. 75, no. 9, p. 1549–1552. [Also available at http://dx.doi.org/10.1139/z97-781.]

Kreeger, T.J., Kuechle, V.B., Mech, L.D., Tester, J.R., and Seal, U.S., 1990, Physiological monitoring of gray wolves (*Canis lupus*) by radiotelemetry: Journal of Mammalogy, v. 71, no. 2, p. 259–261. [Also available at http://dx.doi.org/10.2307/1382180.]

Kunkel, K.E., and Mech, L.D., 1994, Wolf and bear predation on white-tailed deer fawns in northeastern Minnesota: Canadian Journal of Zoology, v. 72, no. 9, p. 1557–1565. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z94-207.]

McRoberts, R.E., Mech, L.D., and Peterson, R.O., 1995, The cumulative effect of consecutive winters' snow depth on moose and deer populations—A defense: Journal of Animal Ecology, v. 64, no. 1, p. 131–135. [Also available at http://www.jstor.org/stable/5834.]

Mech, L.D., 1966, The wolves of Isle Royale: Washingon, D.C., Department of the Interior, National Park Service, Fauna of the National Parks of the United States, Fauna Series No. 7, 210 p. [Also available at https://archive.org/details/wolvesofisleroya00royal.]

Mech, L.D., 1970, The wolf—The ecology and behavior of an endangered species: Garden City, NY, Natural History Press (Doubleday Publishing Company), American Museum of Natural History, 384 p.

Mech, L.D., 1973, Wolf numbers in the Superior National Forest of Minnesota: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Paper NC–97, 10 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10618.]

Mech, L.D., 1974, Current techniques in the study of elusive wilderness carnivores, *in* Kjemer, Ingbrit, and Bjurholm, Per, eds., Proceedings of the 11th International Congress of Game Biologists, Stockholm, September 3–7, 1973, p. 315–322.

Mech, L.D., 1977a, Population trend and winter deer consumption in a Minnesota wolf pack, *in* Phillips, R.L., and Jonkel, C., eds., Proceedings of the 1975 Predator Symposium: Missoula, MT, Montana Forest and Conservation Experiment Station, p. 55–83.

Mech, L.D., 1977b, Productivity, mortality and population trends of wolves in northeastern Minnesota: Journal of Mammalogy, v. 58, no. 4, p. 559–574. [Also available at http://dx.doi.org/10.2307/1380004.]

Mech, L.D., 1977c, Wolf pack buffer zones as prey reservoirs: Science, v. 198, no. 4314, p. 320–321. [Also available at http://dx.doi.org/10.1126/science.198.4314.320.]

Mech, L.D., 1986, Wolf numbers and population trend in the Superior National Forest, 1967–1985: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Paper NC–270, 6 p. [Also available at http://www.nrs.fs.fed.us/pubs/rp_rp_nc270.pdf.]

Mech, L.D., 1987, Age, season, and social aspects of wolf dispersal from a Minnesota pack, *in* Chepko-Sade, B.D., and Halpin, Z.T., eds., Mammalian dispersal patterns: Chicago, University of Chicago Press, p. 55–74.

Mech, L.D., 1988, Longevity in wild wolves: Journal of Mammalogy, v. 69, no. 1, p. 197–198. [Also available at http://dx.doi.org/10.2307/1381776.]

Mech, L.D., 1994, Buffer zones of territories of gray wolves as regions of intraspecific strife: Journal of Mammalogy, v. 75, no. 1, p. 199–202. [Also available at http://dx.doi.org/10.2307/1382251.]

Mech, L.D., 2006a, Age-related body mass and reproductive measurements of gray wolves in Minnesota: Journal of Mammalogy, v. 87, no. 1, p. 80–84.

Mech, L.D., 2006b, Estimated age structure of wolves in northeastern Minnesota: Journal of Wildlife Management, v. 70, no. 5, p. 1481–1483. [Also available at http://www.jstor.org/stable/4128071.]

Mech, L.D., 2007, Femur-marrow fat of white-tailed deer fawns killed by wolves: Journal of Wildlife Management, v. 71, no. 3, p. 920–923. [Also available at http://dx.doi.org/10.2193/2006-153.]

Mech, L.D., 2009, Long-term research on wolves in the Superior National Forest, *in* Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., Recovery of gray wolves in the Great Lakes region of the United States—An endangered species success story: New York, Springer Science+Business Media, p. 15–34. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1_2.]

Mech, L.D., Chapman, R.C., Cochran, W.W., Simmons, Lee, and Seal, U.S., 1984, Radio-triggered anesthetic-dart collar for recapturing large mammals: Wildlife Society Bulletin, v. 12, no. 1, p. 69–74. [Also available at http://www.jstor.org/stable/3781508.]

Mech, L.D., and Federoff, N.E., 2002, α_1-Antitrypsin polymorphism and systematics of eastern North American wolves: Canadian Journal of Zoology, v. 80, no. 5, p. 961–963. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/z02-066.]

Mech, L.D., and Frenzel, L.D., Jr., eds., 1971, Ecological studies of the timber wolf in northeastern Minnesota: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Paper NC–52, 62 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10573.]

Mech, L.D., Frenzel, L.D., Jr., and Karns, P.D., 1971, The effect of snow conditions on the vulnerability of white-tailed deer in wolf predation, *in* Mech, L.D., and Frenzel, L.D., Jr., eds., Ecological studies of the timber wolf in northeastern Minnesota: St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Forest Service Research Paper NC–52, p. 51–59. [Also available at http://www.treesearch.fs.fed.us/pubs/10573.]

Mech, L.D., Frenzel, L.D., Jr., Karns, P.D., and Kuehn, D.W., 1970, Mandibular dental anomalies in white-tailed deer from Minnesota: Journal of Mammalogy, v. 51, no. 4, p. 804–806. [Also available at http://dx.doi.org/10.2307/1378309.]

Mech, L.D., Fritts, S.H., and Wagner, Douglas, 1995, Minnesota wolf dispersal to Wisconsin and Michigan: American Midland Naturalist, v. 133, no. 2, p. 368–370. [Also available at http://dx.doi.org/10.2307/2426402.]

Mech, L.D., and Gese, E.M., 1992, Field testing the Wildlink Capture Collar on wolves: Wildlife Society Bulletin, v. 20, no. 2, p. 249–256. [Also available at http://www.jstor.org/stable/3782899.]

Mech, L.D., and Goyal, S.M., 2011, Parsing demographic effects of canine parvovirus on a Minnesota wolf population: Journal of Veterinary Medicine and Animal Health, v. 3, no. 2, p. 27–30. [Also available at http://www.academicjournals.org/journal/JVMAH/article-full-text-pdf/BD0AF9E3485.]

Mech, L.D., and Harper, E.K., 2002, Differential use of a wolf, *Canis lupus*, pack territory edge and core: Canadian Field Naturalist, v. 116, no. 2, p. 315–316. [Also available at http://wolf.org/wp-content/uploads/2013/09/264differentialuse.pdf.]

Mech, L.D. and Hertel, H.H., 1983, An eight-year demography of a Minnesota wolf pack, *in* Pulliainen, Erkki, and Sulkava, Seppo, eds, Proceedings of the Third International Theriological Congress, Helsinki, August 15–20, 1982, VI. Symposia on lagomorphs, beaver, bear, wolf, and mustelids: Acta Zoologica Fennica, v. 174, p. 249–250.

Mech, L.D., and Karns, P.D., 1977, Role of the wolf in a deer decline in the Superior National Forest: St. Paul, MN, U.S. Department of Agriculture, North Central Forest Experiment Station, Forest Service Research Report NC–148, 23 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10669.]

Mech, L.D., Kunkel, K.E., Chapman, R.C., and Kreeger, T.J., 1990. Field testing of commercially manufactured capture collars on wild deer: Journal of Wildlife Management, v. 54, no. 2, p. 297–299. [Also available at http://www.jstor.org/stable/3809045.]

Mech, L.D., and McRoberts, R.E., 1990, Survival of white-tailed deer fawns in relation to maternal age: Journal of Mammalogy, v. 71, no. 3, p. 465–467. [Also available at http://dx.doi.org/10.2307/1381963.]

Mech, L.D., McRoberts, R.E., Peterson, R.O., and Page, R.E., 1987a, Relationship of deer and moose populations to previous winters' snow: Journal of Animal Ecology, v. 56, no. 2, p. 615–627. [Also available at http://dx.doi.org/10.2307/5072.]

Mech, L.D., Nelson, M.E., and McRoberts, R.E., 1991, Maternal and grandmaternal nutrition effects on deer mass and vulnerability to wolf predation: Journal of Mammalogy, v. 72, no. 1, p. 146–151. [Also available at http://www.jstor.org/stable/1381989.]

Mech, L.D., Seal, U.S., and DelGiudice, G.D., 1987b, Use of urine in the snow to indicate condition of wolves: Journal of Wildlife Management, v. 51, no. 1, p. 10–13. [Also available at http://dx.doi.org/10.2307/3801620.]

Mech, L.D., and Tracy, Shaun, 2004, Record high wolf, *Canis lupus*, pack density: Canadian Field Naturalist, v. 118, no. 1, p. 127–129. [Also available at http://journals.sfu.ca/cfn/index.php/cfn/article/view/896.]

Meier, T.J., Burch, J.W., Mech, L.D., and Adams, L.G., 1995, Pack structure dynamics and genetic relatedness among wolf packs in a naturally-regulated population, *in* Carbyn, L.D., Fritts, S.H., and Seip, D.R., eds., Ecology and conservation of wolves in a changing world: Edmonton, Alberta, Canadian Circumpolar Institute, Occasional Publication 35, p. 293–302.

Merrill, S.B., Adams, L.G., Nelson, M.E., and Mech, L.D., 1998, Testing releasable GPS radiocollars on wolves and white-tailed deer: Wildlife Society Bulletin, v. 26, no. 4, p. 830–835. [Also available at http://www.jstor.org/stable/3783557.]

Merrill, S.B., and Mech, L.D., 2000, Details of extensive movements by Minnesota wolves (*Canis lupus*): American Midland Naturalist, v. 144, no. 2, p. 428–433. [Also available at http://www.jstor.org/stable/3082950.]

Messier, Francois, 1995, Is there evidence for a cumulative effect of snow on moose and deer populations?: Journal of Animal Ecology, v. 64, no. 1, p. 136–140. [Also available at http://dx.doi.org/10.2307/5835.]

Mohr, C.O., 1947, Table of equivalent populations of North American small mammals: American Midland Naturalist, v. 37, no. 1, p. 223–249. [Also available at http://dx.doi.org/10.2307/2421652.]

Murie, Adolph, 1944, The wolves of Mount McKinley: Washington, D.C., U.S. Department of the Interior, National Park Service, Fauna of the National Parks of the United States, Fauna Series No. 5, 238 p.

Musiani, Marco, Mamo, Charles, Boitani, Luigi, Callaghan, Carolyn, Gates, C.C., Mattei, Livia, Visalberghi, Elisabetta, Breck, Stewart, and Volpi, Giulia, 2003, Wolf depredation trends and the use of fladry barriers to protect livestock in western North America: Conservation Biology, v. 17, no. 6, p. 1538–1547. [Also available at http://www.jstor.org/stable/3588902.]

Nagy, K.A., 1994, Field bioenergetics of mammals—What determines field metabolic rates: Australian Journal of Zoology, v. 42, no. 1, p. 43–53. [Also available at http://www.publish.csiro.au/paper/ZO9940043.htm.]

Nelson, M.E., 1993, Natal dispersal and gene flow in white-tailed deer in northeastern Minnesota: Journal of Mammalogy, v. 74, no. 2, p. 316–322. [Also available at http://dx.doi.org/10.2307/1382386.]

Nelson, M.E., and Mech, L.D., 1981, Deer social organization and wolf predation in northeastern Minnesota: Wildlife Monographs No. 77, 53 p. [Also available at http://www.jstor.org/stable/i294121.]

Nelson, M.E., and Mech, L.D., 1986a, Deer population in the central Superior National Forest, 1967–1985: St. Paul, MN, U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Forest Service Research Paper NC–271, 7 p. [Also available at http://www.treesearch.fs.fed.us/pubs/10058.]

Nelson, M.E., and Mech, L.D., 1986b, Mortality of white-tailed deer in northeastern Minnesota: Journal of Wildlife Management, v. 50, no. 4, p. 691–698. [Also available at http://dx.doi.org/10.2307/3800983.]

Nelson, M.E., and Mech, L.D., 1986c, Relationship between snow depth and gray wolf predation on white-tailed deer: Journal of Wildlife Management, v. 50, no. 3, p. 471–474. [Also available at http://dx.doi.org/10.2307/3801108.]

Nelson, M.E., and Mech, L.D., 1987, Demes within a northeastern Minnesota deer population, *in* Chepko-Sade, B.D., and Halpin, Z.T., eds., Mammalian dispersal patterns—The effects of social structure on population genetics: Chicago, University of Chicago Press, p. 27–40.

Nelson, M.E., and Mech, L.D., 1990, Weights, productivity, and mortality of old white-tailed deer: Journal of Mammalogy, v. 71, no. 4, p. 689–691. [Also available at http://dx.doi.org/10.2307/1381809.]

Nelson, M.E., and Mech, L.D., 1991, Wolf predation risk associated with white-tailed deer movements: Canadian Journal of Zoology, v. 69, no. 10, p. 2696–2699.

Nelson, M.E., and Mech, L.D., 2006, A 3-decade dearth of deer (*Odocoileus virginianus*) in a wolf (*Canis lupus*)-dominated ecosystem: American Midland Naturalist, v. 155, no. 2, p. 373–382. [Also available at http://www.jstor.org/stable/4094652.]

Olson, S.F., 1938, Organization and range of the pack: Ecology, v. 19, no. 1, p. 168–170. [Also available at http://www.jstor.org/stable/1930384.]

Packard, J.M., Mech, L.D., and Seal, U.S., 1983, Social influences on reproduction in wolves *in* Carbyn, L.N., ed., Wolves in Canada and Alaska—Their status, biology, and management: Ottowa, Ontario, Canadian Wildlife Service, Proceedings of the Canadian Wolf Workshop, Edmonton, Alberta, May 12–14, 1981, Canadian Wildlife Service Report Series no. 45, p. 78–85.

Packard, J.M., Seal, U.S., Mech, L.D., and Plotka, E.D., 1985, Causes of reproductive failure in two family groups of wolves (*Canis lupus*): Zeitschrift für Tierpsychologie, v. 68, p. 24–40. [Also available at http://dx.doi.org/10.1111/j.1439-0310.1985.tb00112.x.]

Peters, R.P., and Mech, L.D., 1975, Scent-marking in wolves—Radio-tracking of wolf packs has provided definite evidence that olfactory sign is used for territory maintenance and may serve for other forms of communication within the pack as well: American Scientist, v. 63, no. 6, p. 628–637. [Also available at http://www.jstor.org/stable/27845779.]

Peterson, R.O., Woolington, J.D., and Bailey, T.N., 1984, Wolves of the Kenai Peninsula, Alaska: Wildlife Monographs No. 88, 52 p. [Also available at http://www.jstor.org/stable/3830728.]

Pimlott, D.H., Shannon, J.A., and Kolenosky, G.B., 1969, The ecology of the timber wolf in Algonquin Provincial Park, Ontario: Toronto, Ontario, Ontario Department of Lands and Forests Research Report (Wildlife) No. 87, 92 p.

Raymer, J.H., Wiesler, D.P., Novotny, M.V., Asa, C.S., Seal, U.S., and Mech, L.D., 1985, Chemical investigations of wolf (*Canis lupus*) anal sac secretions in relation to breeding season: Journal of Chemical Ecology, v. 11, no. 5, p. 593–608. [Also available at http://dx.doi.org/10.1007/BF00988570.]

Raymer, J.H., Wiesler, D.P., Novotny, M.V., Asa, C.S., Seal, U.S., and Mech, L.D., 1986, Chemical scent constituents in urine of wolf (*Canis lupus*) and their dependence on reproductive hormones: Journal of Chemical Ecology, v. 12, no. 1, p. 297–313. [Also available at http://dx.doi.org/10.1007/BF01045612.]

Ream, R.R., Fairchild, M.W., Boyd, D.K., and Pletscher, D.H., 1991, Population dynamics and home range changes in a colonizing wolf population, *in* Keiter, R.K., and Boyce, M.S., eds., The greater Yellowstone ecosystem—Redefining America's wilderness heritage: New Haven, CT, Yale University Press, p. 349–366.

Rothman, R.J., and Mech, L.D., 1979, Scent-marking in lone wolves and newly formed pairs: Animal Behaviour, v. 27, no. 3, p. 750–760. [Also available at http://dx.doi.org/10.1016/0003-3472(79)90010-1.]

Schultz, R.N., Jonas, K.W., Skuldt, L.H., and Wydeven, A.P., 2005, Experimental use of dog-training shock collars to deter depredation by gray wolves: Wildlife Society Bulletin, v. 33, no. 1, p. 142–148. [Also available at http://www.jstor.org/stable/3784849.]

Seal, U.S.,. Erickson, A.W., and Mayo, J.G., 1970, Drug immobilisation of the Carnivora: International Zoological Yearbook, v. 10, no. 1, p. 157–170. [Also available at http://www.dx.doi/10.1111/j.1748-1090.tb01324.x.]

Seal, U.S., and Mech, L.D., 1983, Blood indicators of seasonal metabolic patterns in captive adult gray wolves: Journal of Wildlife Management, v. 47, no. 3, p. 704–715. [Also available at http://dx.doi.org/10.2307/3808606.]

Seal, U.S., Mech, L.D., and Van Ballenberghe, Victor, 1975, Blood analyses of wolf pups and their ecological and metabolic interpretation: Journal of Mammalogy, v. 56, no. 1, p. 64–75. [Also available at http://dx.doi.org/10.2307/1379606.]

Seal, U.S., Nelson, M.E., Mech, L.D., and Hoskinson, R.L., 1978, Metabolic indicators of habitat differences in four Minnesota deer populations: Journal of Wildlife Management, v. 42, no. 4, p. 746–754. [Also available at http://dx.doi.org/10.2307/3800765.]

Seal, U.S., Plotka, E.D., Mech, L.D., and Packard, J.M., 1987, Seasonal metabolic and reproductive cycles in wolves, *in* Frank, H., ed., Man and wolf—Advances, issues, and problems in captive wolf research: Boston, Dr. W. Junk Publishers, p. 109–125.

Shivik, J.A., 2006, Tools for the edge—What's new for conserving carnivores: BioScience, v. 56, no. 3, p. 253–259. [Also available at http://bioscience.oxfordjournals.org/content/56/3/253.full.]

Stenlund, M.H., 1955, A field study of the timber wolf (*Canis lupus*) on the Superior National Forest: Minnesota Department of Conservation Technical Bulletin, v. 4, 55 p.

Van Ballenberghe, Victor, Erickson, A.W., and Byman, David, 1975, Ecology of the timber wolf in northeastern Minnesota: Wildlife Monographs No. 43, p. 3–43. [Also available at http://www.jstor.org/stable/3830388.]

Verme, L.J., 1968, An index of winter weather severity for northern deer: Journal of Wildlife Management, v. 32, no. 3, p. 566–574. [Also available at http://dx.doi.org/10.2307/3798937.]

Vucetich, J.A., and Peterson, R.O., 2009, Wolf and moose dynamics on Isle Royale, *in* Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., Recovery of gray wolves in the Great Lakes Region of the United States—An endangered species success story: New York, Springer Science+Business Media, p. 35–48. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1_3.]

Weise, T.F., Robinson, W.L., Hook, R.A., and Mech, L.D., 1979, An experimental translocation of the eastern timber wolf, *in* Klinghammer, Erich, ed., The behavior and ecology of wolves: New York, Garland STPM Press, p. 346–419.

Wilson, P.J., Grewal, Sonya, Lawford, I.D., Heal, J.N.M., Granacki, A.G., Pennock, David, Theberge, J.B., Theberge, M.T., Voigt, D.R., Waddell, Will, Chambers, R.E., Paquet, P.C., Goulet, Gloria, Cluff, Dean, and White, B.N., 2000, DNA profiles of the eastern Canadian wolf and the red wolf provide evidence for a common evolutionary history independent of the gray wolf: Canadian Journal of Zoology, v. 78, no. 12, p. 2156–2166. [Also available at http://dx.doi.org/10.1139/z00-158.]

Wilson, P.J., Grewal, S.K., Mallory, F.F., and White, B.N., 2009, Genetic characterization of hybrid wolves across Ontario: Journal of Heredity, v. 100, suppl. 1, p. S80–S89. [Also available at http://dx.doi.org/10.1093/jhered/esp034.]

Wydeven, A.P., Van Deelen, T.R., and Heske, E.J., eds., 2009, Recovery of gray wolves in the Great Lakes Region of the United States—An endangered species success story: New York, Springer Science+Business Media, 350 p. [Also available at http://dx.doi.org/10.1007/978-0-387-85952-1.]

Muskrat (*Ondatra zibethicus*) on water, Patuxent Research Refuge, Laurel, MD, 1980. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Wildlife Disease Studies at Patuxent

Glenn H. Olsen

The study of wildlife diseases has always been part of the mission of the Patuxent Wildlife Research Center (Patuxent), in Laurel, MD. Indeed, when the original lands were being chosen and developed, personnel of the U.S. Department of Agriculture, Bureau of Animal Industry, Pathological Division, criticized the location of the facility. They believed that establishment of a wildlife demonstration and research area by the Bureau of Biological Survey in the vicinity of the planned Beltsville Agricultural Research Center could lead to a disease hazard (Morley, 1948, p. 4). Dr. Leland C. Morley, a veterinarian by training, was the first superintendent of Patuxent Research Refuge. Dr. Morley's appointment and his move into the refuge's first offices (and residence), known as the Log Cabin, occurred 7 months before President Franklin D. Roosevelt signed Executive Order No. 7514 on December 16, 1936, officially establishing the Patuxent Research Refuge. The Log Cabin residence had been acquired by the Federal government in April 1936.

The first captive wildlife research flock was established in the spring of 1936, predating the official opening of Patuxent. This flock consisted of northern bobwhite (*Colinus virginianus*), which were received from the Section of Disease Control of the University of Maryland, demonstrating that the cooperative ties between Patuxent and the university date back to the earliest days of Patuxent. These quail were used in the first experimental work done at Patuxent by biologist Phoebe Knappen (Morley, 1948, p. 17), who studied the acceptability and toxicity of various natural seeds and berries that were considered at the time to be important quail food. The first Patuxent publication about wildlife disease—"Diseases of Upland Game Birds (part 5)" by J.E. Shillinger and L.C. Morley (1941), published in "Game Breeder and Sportsman"—resulted partly from quail studies. This paper was followed by U.S. Fish and Wildlife Service (USFWS) Bulletin 21, "Diseases of Upland Game Birds," also by Shillinger and Morley (1942).

With the help of the Civilian Conservation Corps (CCC), kennels with litter boxes were constructed to house fur-bearing animals for disease research. Thirty foxes and an unspecified number of ferrets and mink were acquired for this work (Morley, 1948, p. 17). In 1938, Phoebe Knappen and Franklin H. May, an employee of the Section of Food Habits of the Department of Agriculture, studied the effects of orchard sprays on birds (Morley, 1948, p. 29). By this time, a Section of Disease Control had been established at Patuxent, and experimental facilities for this section were expanded. Also in 1938, Dr. Morley hired two additional veterinarians, Dr. Don R. Coburn (who started September 21, 1938) and Dr. William H. Armstrong (who started October 17, 1938). In 1942, Patuxent published five papers with either Dr. Coburn or Dr. Armstrong as the lead author. The subjects of these early research papers ranged from *Salmonella* in muskrats (*Ondatra zibethicus*) (Armstrong, 1942) and chinchillas (*Chinchilla* sp.) (Coburn and others, 1942) to canine distemper in a zoological park (Armstrong and Anthony, 1942).

In 1939, funds were requested for construction of a barn and greenhouse, but it was decided instead to build a laboratory for Patuxent's newly named Unit of Disease Investigations. Because the original intent had been to build a barn, the architect, Munk Pederson, designed the building to appear plain and barn-like. This is why Henshaw Laboratory was set into the hillside with a second-story entrance on one side and a first-floor entrance on the other. The new building included a large greenhouse that was used for other nondisease studies. The building remains plain in appearance, with small windows and doors, and is more barn-like than Nelson and Merriam Laboratories, whose architecture is more ornate (Morley, 1948, p. 30).

The Unit of Disease Investigations employed the following people in the early days of Patuxent:

Personnel	Position	Dates of employment
William H. Armstrong	Veterinarian	10/17/38–8/7/42
Helen M. Churchill	Bacteriologist	10/8/42–3/31/45
Don R. Coburn	Veterinarian	9/21/38–?
Phoebe Knappen	Biologist	7/1/40–6/28/42
Erling Quartrop	Veterinarian	4/28/45–6/29/46
Psyche W. Wetmore	Bacteriologist	6/1/39–7/23/42
Ralph B. Nestler	Biologist	6/1/42–?

Lumber for construction of this building and all early buildings, except Merriam Laboratory, came from two sawmills set up on Patuxent property to process trees harvested from the site of Cash Lake and downed timber along the Patuxent River bottomlands. The Patuxent sawmills were so effective that some wood was harvested and shipped to Washington, D.C., for construction projects there (Morley, 1948, p. 33). The sand and gravel used in the cement for all construction came from an open gravel pit at Patuxent.

Seventeen papers on wildlife diseases—eight on mammalian wildlife diseases and nine on avian wildlife diseases—were published by Patuxent authors during 1942–49. Arnold L. Nelson, Director of the Patuxent Research Refuge, described the work of the Wildlife Pathology Laboratory in the Bulletin for Medical Research in 1959. He said that Patuxent scientists had been working to identify diseases of wildlife and the agents causing the diseases, and indicated that "Little information exists however, on pathology, significance of disease-causing organisms on the welfare of the host, mechanisms of infection and spread, relationship between wildlife diseases and environmental stress and methods by which an effective attack can be launched to control disease" (Nelson, 1959). He described studies of Canada goose (*Branta canadensis*) mortality resulting from gizzard worms at Pea Island National Wildlife Refuge in North Carolina. Patuxent scientists also were studying diseases of waterfowl, especially aspergillosis, the diseases of icteric birds (blackbirds), and the relations of stress factors to infectious diseases and parasite infestation during the 1950s (Nelson, 1959). Trichomoniasis in mourning doves (*Zenaida macroura*) also was being studied, with an emphasis on mode of infection and immunity factors (Nelson, 1959).

Nelson acknowledged that the study of mammalian diseases was much more limited. He mentioned two ongoing studies, one on the parasites found on mammals at the Patuxent Research Refuge and the other on distemper in wild mammals (Nelson, 1959). Also at this time, staff at the Walter Reed Army Institute of Research in Silver Spring, MD, were studying wildlife diseases that were considered zoonotic—that is, diseases that spread between animals and humans. This work was conducted at Fort George G. Meade Army Post, on land that is now part of Patuxent Research Refuge. Patuxent scientists published 36 papers on wildlife diseases in the 1950s; 15 of these were on mammalian diseases and 21 were on avian diseases.

Diseases caused by toxicological agents, namely pesticides, became an area of concern for wildlife populations in the 1940s, and Patuxent began studies at that time. The program increased in scope under the leadership of Dr. John L. Buckley, Patuxent's director from 1959 until 1963, and was renamed the Environmental Contaminants Research Program to distinguish it from the study of wildlife diseases caused by other agents. More emphasis was placed on statistically rigorous controlled experiments. In 1962, the bestselling book "Silent Spring" by Rachel Carson (Carson, 1962) highlighted this type of threat to wildlife. In 1963, Secretary of the Interior Stewart Udall dedicated a new building at Patuxent, named the "Biochemistry and Wildlife Pathology Laboratory" to indicate its dual role. The building housed state-of-the-art necropsy facilities to further the study of wildlife diseases.

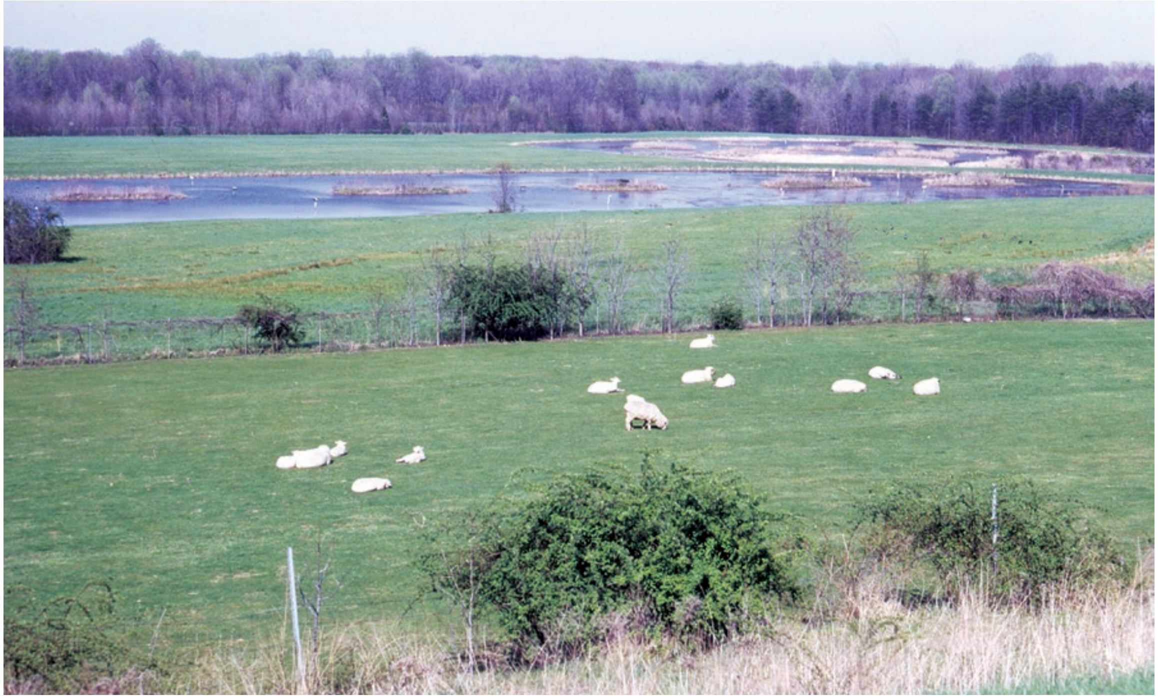
The study of lead poisoning in waterfowl also was begun in the 1960s. Louis N. Locke and George E. Bagley (1967) published the first report from Patuxent on lead poisoning, "Coccidioses and lead poisoning in Canada geese," in the journal "Chesapeake Science." The study of lead toxicity in wildlife continued (Heinz, 2016) with more recent work by Nimish Vyas, who studied lead poisoning in passerines from skeet shooting ranges in the early years of the 21st century (Vyas and others, 2000). In 1969, Locke and others (1969) published another important lead study that identified lead poisoning as a mortality factor in condors. This work was conducted at Patuxent by using captive Andean condors (*Vultur gryphus*) as a surrogate for the endangered California condor (*Gymnogyps californianus*).

Another development in the 1960s that had a large effect on wildlife disease studies at Patuxent was the establishment of an endangered species research program that included not only field research, but captive breeding programs for at least eight species, including masked bobwhite (*Colinus virginianus ridgwayi*), bald eagles (*Haliaeetus leucocephalus*), Mississippi sandhill cranes (*Grus canadensis pulla*), whooping cranes (*Grus americana*), and Puerto Rican parrots (*Amazona vittata*) in addition to the Andean condors.

Also in the 1960s, the role of parasites as disease agents in wildlife began to receive greater emphasis in Patuxent research (Herman, 1966). Carlton Herman, a parasitologist, eventually became leader of the Wildlife Disease Section, as it was called in the 1960s–70s. Richard Kocan, another parasitologist, worked on trichomoniasis in mourning doves (Kocan, 1971), and Barry Tarshis, Herman, and Kocan worked on the relation of black flies (*Simulium nigricoxum*) and leucocytozoon infestations (Tarshis and Herman, 1965; Kocan, 1968a, 1968b; Kocan and Barrow, 1968; Herman, 1969b).

In the 1960s, Patuxent scientists produced a total of 67 wildlife-disease-centered publications—52 on avian species, 8 on mammalian species, and 7 on the general topic of wildlife disease. Included among these publications is the chapter by Herman on "Bird-borne Diseases in Man" (Herman, 1969a) in the first comprehensive veterinary textbook on pet birds, "Diseases of Cage and Avian Birds," edited by Margaret L. Petrak (1969). Other notable wildlife disease research included work on viruses that cause eastern equine encephalitis and myxovirus in deer plus duck viral enteritis (duck plague).

The start of the Endangered Species Program caused a shift in emphasis in the study of wildlife diseases owing to the presence of live animals in pens at Patuxent for long-term (10 or more years) rather than periodic (1–3 years) research studies. Starting in 1970, a veterinary hospital was located in a double-wide trailer on a dead-end road off the loop road in the endangered species area. A veterinarian was hired to manage the clinical care of the endangered species. James Brown, the



Domestic sheep maintained at Patuxent Wildlife Research Center, Laurel, MD, for disease studies, 1972. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

first veterinarian to work in this position, was followed by James Carpenter, who came in 1975. Louis Sileo (1976–83) and Louis Locke worked at the Patuxent environmental contaminants research laboratory. Sileo and others (1983) reported on a die-off of captive kestrels at Patuxent attributed to hemorrhagic enteritis and hepatitis.

In 1975, wildlife disease study at Patuxent experienced a major shift. A new laboratory to study wildlife diseases, the National Wildlife Health Center, was established in Madison, WI, as part of the efforts of the USFWS (later U.S. Geological Survey [USGS]) to better diagnose and fight disease outbreaks at wildlife refuges across the country. Over the next two decades, many Patuxent staff members migrated to this new laboratory, and general wildlife disease research at Patuxent ended, though research on wildlife diseases caused by environmental contaminants and those affecting endangered species continued.

In the 1970s, the number of publications fell precipitously as a result of the move of many members of the wildlife disease research staff from Patuxent to Madison. From 1970 through 1974 (before the move), 38 papers were published—33 on avian wildlife disease studies and 5 on general wildlife disease subjects. From 1975 through 1979, only 13 papers were published—3 on mammalian diseases and 10 on avian diseases. This decrease in the number of publications on wildlife diseases demonstrates more than anything else the shift in program emphasis on wildlife disease research away from Patuxent. Wildlife disease publications during the 1970s included 43 on avian disease, 3 on mammalian disease, and 5 on the general topic of wildlife diseases, for a total of 51 papers; however, papers continued to be published on trichomoniasis (Kocan, 1971) and plasmodium (Kocan and Perry, 1976) infections. Several papers were published on avian cholera (Locke and Banks, 1972; Locke and others, 1972). Several publications in the latter half of the 1970s

Dan Day and Glenn Olsen, U.S. Fish and Wildlife Service, inspecting a sandhill crane in the old trailer veterinary hospital at Patuxent Wildlife Research Center, Laurel, MD, 1988. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Jane Chandler and Glenn Olsen, U.S. Geological Survey, inspecting a whooping crane in new veterinary hospital at Patuxent Wildlife Research Center, Laurel, MD, 1996. Photo by U.S. Geological Survey.

about parasites in cranes (Forrester and others, 1978; Carpenter and others, 1979) and endangered black-footed ferrets (*Mustela nigripes*) (Carpenter and Novilla, 1977; Carpenter and others, 1976) demonstrate the shift toward wildlife disease studies involving the captive endangered species colonies at Patuxent.

Wildlife disease studies at Patuxent in the 1980s focused on two species, whooping cranes and gray wolves (*Canis lupus*). The whooping crane disease research focused on two diseases—disseminated visceral coccidiosis, which occurs naturally in cranes, but was seen in increased numbers because of captive rearing (Carpenter and Novilla, 1980; Carpenter and others, 1980; Novilla and others, 1981; Carpenter and others, 1984); and eastern equine encephalitis, which developed suddenly in 1984, killing seven whooping cranes (Carpenter and others, 1985; Carpenter and others, 1986; Dein and others, 1986). Dr. L. David Mech was hired to manage the endangered species Minnesota field station working with gray wolves. He was a former graduate student of Durward Allen, a Patuxent wildlife research biologist in the 1940s, who had moved on to Purdue University of Indiana. Mech, in his wolf research, collaborated with Ulysses S. Seal (Veterans Administration Medical Center, Minneapolis, MN) and others about disease research and immobilization techniques (Mech and others, 1984, 1985, 1986; Kreeger and others, 1987).

Additions to the Patuxent research staff in the 1980s included Chris Franson (1979–84), a veterinarian, who worked with the environmental contaminants program. Joshua Dein (1984–87) joined the Patuxent Endangered Species Program as a veterinarian and helped develop the first institutional animal care and use committee. When Dein and Franson departed to join the staff at the USGS National Wildlife Health Center, Glenn H. Olsen was hired (1987–present [2016]) to work in clinical veterinary medicine (50 percent) and research (50 percent). Beginning in the late 1980s, Olsen and Carpenter planned and drafted the blueprints for a new Patuxent Veterinary Hospital that opened on December 3, 1994; it was partly funded by Baltimore Gas and Electric Company.

Published papers on wildlife diseases in the 1980s totaled 39—25 on avian diseases and 14 on mammalian diseases. Patuxent also hired a nutritionist, John A. Serafin (1980–82), who worked with the Endangered Species Program and published several papers on nutritional diseases (Serafin, 1981, 1982, 1983).

The 1990s was a decade of changes for Patuxent and certainly for wildlife disease research. In 1994, Patuxent joined the National Biological Survey and gained several field stations. From a wildlife disease standpoint, the most important of these was arguably a former National Park Service field station colocated at the University of Rhode Island in Kingston. Howard S. Ginsberg (1994–present [2016]), a medical entomologist, joined Patuxent at this field station. In 1990, Dr. Carpenter left Patuxent for Kansas State University. In 1991, Patrice N. Klein (1991–95) was hired as a veterinarian to work in pathology and clinical medicine. In October 1996, Patuxent joined the USGS. In 1994, a new veterinary hospital was opened in a 3,000-square-foot building 0.2 miles west of Gabrielson Laboratory. In addition to serving the needs of Patuxent's captive wildlife, the facility has been used for many research projects.

Forty-one papers that originated at Patuxent were published on wildlife diseases from 1990 to 1999—19 on avian diseases, 9 on mammalian diseases, 12 on general wildlife diseases, and 1 on diseases of turtles. During this decade, Patuxent initiated a more intensive monitoring and research program involving reptiles and amphibians and published one paper on shell diseases in turtles (Lovich and others, 1996). Other important publications include a paper on mycotoxin-related epizootic disease in the captive crane colony (Olsen

Thom Lewis and James Carpenter, U.S. Fish and Wildlife Service, force feed with gavage a sandhill crane, Patuxent Wildlife Research Center, Laurel, MD, 1981. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

and others, 1995); several papers on Lyme disease; and a book, "Ecology and Environmental Management of Lyme Disease," edited by Howard S. Ginsberg (1993). Papers on wildlife diseases in endangered species, primarily wolves and cranes, continued to predominate, along with those on Lyme disease. Several papers were published on new techniques that would be used in future programs (Olsen and others, 1990; Olsen, 1999). One techniques paper on surgically implanting radio transmitters in ducks (Olsen and others, 1992) led to the development of an entirely new method of research on duck populations, especially far-ranging seaducks (Olsen and others, 2005).

In the first decade of the 21st century, research on wildlife diseases continued at Patuxent and at field locations around the world. Since 2005, the veterinary staff has been actively involved with implanting platform transmitting terminals (PTTs), also called satellite radio transmitters. Most of this work has been in support of various projects funded by the Sea Duck Joint Venture, a multiagency group supporting seaduck conservation, but some work has involved learning more about the habits of seaducks in relation to licensing of sites for offshore wind energy. Another important area of study with implant and backpack PTTs has been a project on avian influenza in Eurasia and Africa, and the potential for this disease to be transmitted by migrating waterfowl (Prosser and others, 2011).

Another emerging disease of this decade (2000–10) was West Nile virus, and Patuxent researchers were active in this area, studying the vectors of transmission (Ginsburg, 1993), the effect of the virus on endangered species, and possible methods for prevention through vaccination (Olsen and others, 2009).

Patuxent has had a long and distinguished history of research on diseases of wildlife. Although much of the leading role in this area changed owing to the formation of the National Wildlife Health Center, Madison, WI, Patuxent still (2016) does major investigations dealing with disease, especially in regard to diseases of the Patuxent captive colonies of endangered species and other wildlife. Patuxent veterinarians maintain close contact with the veterinarians at the Health Center and collaborate on many field studies that focus on diseases.

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References Cited

Armstrong, W.H., 1942, Occurrence of *Salmonella typhimurium* infection in muskrats: Cornell Veterinarian, v. 32, no. 1, p. 87–89. [Also available at https://babel.hathitrust.org/cgi/pt?id=uc1.b4179367;view=1up;seq=99.]

Armstrong, W.H., and Anthony, C.H., 1942, An epizootic of canine distemper in a zoological park: Cornell Veterinarian, v. 32, no. 3, p. 286–288. [Also available at https://babel.hathitrust.org/cgi/pt?id=uc1.b4179367;view=1up;seq=300.]

Carpenter, J.W., Appel, M.J.G., Erickson, R.C., and Novilla, M.N., 1976, Fatal vaccine-induced canine distemper virus infection in black-footed ferrets: Journal of the American Veterinary Medical Association, v. 169, no. 9, p. 961–964. [Also available at https://www.researchgate.net/publication/22166982_Fatal_vaccine-induced_canine_distemper_virus_infection_in_Black-footed_ferrets.]

Carpenter, J.W., Dein, F.J., and Clark, G.G., 1985, An epizootic of eastern equine encephalitis virus in whooping cranes: American Association of Zoo Veterinarians, Annual Conference Proceedings, p. 80 (abstract).

Carpenter, J.W., Dein, F.J., Clark, G.C., Watts, D.M., and Crabbs, C.L., 1986, Use of an inactivated eastern equine encephalitis virus vaccine in cranes: American Association of Zoo Veterinarians, Annual Conference Proceedings, p. 88 (abstract).

Carpenter, J.W., and Novilla, M.N., 1977, Diabetes mellitus in a black-footed ferret: Journal of the American Veterinary Medical Association, v. 171, no. 9, p. 890–893. [Also available at https://www.researchgate.net/publication/22229819_Diabetes_mellitus_in_a_black-footed_ferret.]

Carpenter, J.W., and Novilla, M.N., 1980, The occurrence and control of disseminated visceral coccidiosis in captive cranes: American Association of Zoo Veterinarians, Annual Conference Proceedings, p. 99–101.

Carpenter, J.W., Novilla, M.N., Fayer, R., and Iverson, G.C., 1984, Disseminated visceral coccidiosis in sandhill cranes: Journal of the American Veterinary Medical Association, v. 185, no. 11, p. 1343–1346. [Abstract available at http://www.ncbi.nlm.nih.gov/pubmed/6511579.]

Carpenter, J.W., Spraker, T.R., Gardiner, C.H., and Novilla, M.N., 1979, Disseminated granulomas caused by an unidentified protozoan in sandhill cranes: Journal of the American Veterinary Medical Association, v. 175, no. 11, p. 948–951. [Abstract available at http://www.ncbi.nlm.nih.gov/pubmed/521379.]

Carpenter, J.W., Spraker, T.R., and Novilla, M.N., 1980, Disseminated visceral coccidiosis in whooping cranes: Journal of the American Veterinary Medical Association, v. 177, no. 9, p. 845–848. [Abstract available at http://www.ncbi.nlm.nih.gov/pubmed/7451323.]

Carson, R.L., 1962, Silent spring: Boston, MA, Houghton Mifflin, 368 p.

Coburn, D.R., Armstrong, W.H., and Wetmore, P.W., 1942, Observations on bacterin treatment of *Salmonella typhi-murium* infections in chinchillas: American Journal of Veterinary Research, v. 3, no. 6, p. 96.

Dein, F.J., Carpenter, J.W., Clark, G.G., Montali, R.J., Crabbs, C.L., Tsai, T.F., and Docherty, D.E., 1986, Mortality of captive whooping cranes caused by eastern equine encephalitis virus: Journal of the American Veterinary Medical Association, v. 189, no. 9, p. 1006–1010. [Abstract available at http://www.ncbi.nlm.nih.gov/pubmed/3505915.]

Forrester, D.J., Carpenter, J.W., and Blankenship, D.R., 1978, Coccidia of whooping cranes: Journal of Wildlife Diseases, v. 14, no. 1, p. 24–27. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-14.1.24.]

Ginsberg, H.S., ed., 1993, Ecology and environmental management of Lyme disease: New Brunswick, NJ, Rutgers University Press, 224 p.

Heinz, G.H., 2016, Patuxent researchers tackle heavy metal poisoning in wildlife, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 101–106. [Also available at https://doi.org/10.3133/cir1422.]

Herman, C.M., 1966, Birds and our health, *in*, Steufferud, Alfred, and Nelson, A.L., eds., Birds in our lives: Washington, D.C., U.S. Fish and Wildlife Service, p. 284–291.

Herman, C.M., 1969a, Bird-borne diseases in man, *in* Petrak, M.L., ed., Diseases of cage and avian birds: Philadelphia, PA, Lea and Febiger, p. 503–507.

Herman, C.M., 1969b, Blood protozoa of free-living birds, *in* McDiarmid, A., ed., Diseases in free-living wild animals: Symposia of the Zoological Society of London, no. 24, p. 177–193.

Kocan, R.M., 1968a, Anemia and mechanism of erythrocyte destruction in ducks with acute *Leucocytozoon* infections: Journal of Protozoology, v. 15, no. 3, p. 455–462. [Also available at http://onlinelibrary.wiley.com/doi/10.1111/j.1550-7408.1968.tb02156.x/abstract.]

Kocan, R.M., 1968b, The canvasback duck (*Aythya valisineria*)—A new host for *Plasmodium*: Bulletin of the Wildlife Disease Association, v. 4, no. 3, p. 86–87. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-4.3.86.]

Kocan, R.M., 1971, The effect of dexamethasone on immune pigeons infected with various strains of *Trichomonas gallinae*: Journal of Protozoology, v. 18, suppl. 3, abstract 103, p. 30. (abstract) [Also available at http://onlinelibrary.wiley.com/doi/10.1111/jeu.1971.18.issue-s3/issuetoc.]

Kocan, R.M., and Barrow, J.H., Jr., 1968, Observations on the development and significance of *Leucocytozoon simondi* megaloschizonts and a technique for their isolation: Bulletin of the Wildlife Disease Association, v. 4, no. 3, p. 94–95. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-4.3.94.]

Kocan, R.M., and Perry, M.C., 1976, Infection and mortality in captive wild-trapped canvasback ducks: Journal of Wildlife Disease, v. 12, no. 1, p. 30–33. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-12.1.30.]

Kreeger, T.J., Faggella, A.M., Seal, U.S., Mech, L.D., Callahan, M., and Hall, Bruce, 1987, Cardiovascular and behavioral responses of gray wolves to ketamine-xylazine immobilization and antagonism by yohimbine: Journal of Wildlife Diseases, v. 23, no. 3, p. 463–470. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-23.3.463.]

Locke, L.N., and Bagley, G.E., 1967, Case report—Coccidioses and lead poisoning in Canada geese: Chesapeake Science, v. 8, no. 1, p. 68–69. [Also available at http://www.jstor.org/stable/1350358.]

Locke, L.N., Bagley, G.E., Frickie, D.N., and Young, L.T., 1969, Lead poisoning and aspergillosis in an Andean condor: Journal of the American Veterinary Medical Association, v. 155, no. 7, p. 1052–1056.

Locke, L.N., and Banks, R.C., 1972, Avian cholera in cedar waxwings in Ohio: Journal of Wildlife Diseases, v. 8, no. 1, p. 106. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-8.1.106.]

Locke, L.N., Newman, J.A., and Mulhern, B.M., 1972, Avian cholera in a bald eagle from Ohio: Ohio Journal of Science, v. 72, no. 5, p. 294–296. [Also available at http://hdl.handle.net/1811/5725.]

Lovich, J.E., Gotte, S.W., Ernst, C.H., Harshbarger, J.C., and Laemmerzahl, A.F., 1996, Prevalence and histopathology of shell disease in turtles from Lake Blackshear, Georgia: Journal of Wildlife Diseases, v. 32, no. 2, p. 259–265. [Also available at http://dx.doi.org/10.7589/0090-3558-32.2.259.]

Mech, L.D., DelGiudice, G.D., Karns, P.D., and Seal, U.S., 1985, Yohimbine hydrochloride as an antagonist to xylazine hydrochloride-ketamine hydrochloride immobilization of white-tailed deer: Journal of Wildlife Diseases, v. 21, no. 4, p. 405–410. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-21.4.405.]

Mech, LD., Goyal, S.M., Bota, C.N., and Seal, U.S., 1986, Canine parvovirus infection in wolves (*Canis lupus*) from Minnesota: Journal of Wildlife Diseases, v. 22, no. 1, p. 104–106. [Also available at http://www.jwildlifedis.org/doi/abs/10.7589/0090-3558-22.1.104.]

Mech, L.D., Seal, U.S., and Arthur, S.M., 1984, Recuperation of a severely debilitated wolf: Journal of Wildlife Diseases, v. 20, no. 2, p. 166–168. [Also available at http://dx.doi.org/10.7589/0090-3558-20.2.166.]

Morley, L.C., 1948, Early history of Patuxent Wildlife Research Center (circa 1948): Patuxent Wildlife Research Center, 74 p., accessed June 3, 2015, at http://www.pwrc.usgs.gov/history/cronhist/Morley4.pdf.

Nelson, A.L., 1959, The Patuxent Research Refuge: Bulletin for Medical Research, v. 13, no. 1, p. 16–19, 30.

Novilla, M.N., Carpenter, J.W., Spraker, T.R., and Jeffers, T.K., 1981, Parental development of eimerian coccidia in sandhill and whooping cranes: Journal of Protozoology, v. 28, no. 2, p. 248–255. [Also available at http://dx.doi.org/10.1111/j.1550-7408.1981.tb02844.x.]

Olsen, G.H., 1999, Using endoscopy to diagnose hatching problems in cranes: Association of Avian Veterinarians Proceedings, p. 147–148.

Olsen, G.H., Carpenter, J.W., Gee, G.F., Thomas, N.J., and Dein, F.J., 1995, Mycotoxin-induced disease in captive whooping cranes (*Grus americana*) and sandhill cranes (*Grus canadensis*): Journal of Zoo and Wildlife Medicine, v. 26, no. 4, p. 569–576. [Also available at http://www.jstor.org/stable/info/20095525.]

Olsen, G.H., Dein, F.J., Haramis, G.M, and Jorde, D.G., 1992, Implanting radio transmitters in wintering canvasbacks: Journal of Wildlife Management, v. 56, no. 2, p. 325–328. [Also available at http://dx.doi.org/10.2307/3808830.]

Olsen, G.H., Miller, K.J., Docherty, D.E., Bochsler, V.S., and Sileo, Louis, 2009, Pathogenicity of West Nile virus and response to vaccination in sandhill cranes (*Grus canadensis*) using a killed vaccine: Journal of Zoo and Wildlife Medicine, v. 40, no. 2, p. 263–271. [Also available at http://dx.doi.org/10.1638/2008-0017.1.]

Olsen, G.H., Nicolich, J.M., and Hoffman, D.J., 1990, A review of some causes of death of avian embryos: Association of Avian Veterinarians Proceedings, p. 106–111.

Olsen, G.H., Perry, M.C., Wells, A.M., Lohnes, E.J.R., and Osenton, P.C., 2005, The Atlantic Seaduck Project—Medical aspects: Bedford, TX, Association of Avian Veterinarians, Proceedings of the 26th Annual Conference and Expo, Monterey, CA, August 8, 2005, p. 315–318.

Prosser, D.J., Cui, Peng, Takekawa, J.Y., Tang, Mingjie, Hou, Yuansheng, Collins, B.M., Yan, Baoping, Hill, N.J., Li, Tianxian, Li, Yongdong, Lei, Fumin, Guo, Shan, Xing, Zhi, He, Yubang, Zhou, Yuanchun, Douglas, D.C., Perry, W.M., and Newman, S.H., 2011, Wild bird migration across the Qinghai-Tibetan Plateau—A transmission route for highly pathogenic H5N1: PloS One, v. 6, no. 3, p. e17622. [Also available at http://dx.doi.org/10.1371/journal.pone.0017622.]

Serafin, J.A., 1981, Nutritionally-related diseases of captive-reared cranes and ratites: Ithaca, NY, Cornell University, Cornell Nutrition Conference for Feed Manufacturers Proceedings, p. 74–80.

Serafin, J.A., 1982, Reduced mortality among young endangered masked bobwhite quail fed oxytetracycline-supplemented diets: Avian Diseases, v. 26, no. 2, p. 422–425. [Also available at http://www.jstor.org/stable/1590116.]

Serafin, J.A., 1983, Nutrition and disease relationships that may serve as models for feeding oiled birds, *in* Rosie, Don, and Barnes, S.N., eds., The effects of oil on birds—A multi-discipline symposium: Wilmington, DE, Tri-State Bird Rescue and Research, Inc., p. 167–178.

Shillinger, J.E., and Morley, L.C., 1941, Diseases of upland game birds (part 5): Game Breeder and Sportsman, v. 46, no. 9, p. 170–171, 179.

Shillinger, J.E., and Morley, L.C., 1942, Diseases of upland game birds: Washington, D.C., U.S. Fish and Wildlife Service, Conservation Bulletin, no. 21, 32 p.

Sileo, L., Franson, J.C., Graham, D.L., Domermuth, C.H., Rattner, R.A., and Pattee, O.H., 1983, Hemorrhagic enteritis in captive American kestrels (*Falco sparverius*): Journal of Wildlife Diseases, v. 19, no. 3, p. 244–247. [Also available at http://dx.doi.org/10.7589/0090-3558-19.3.244.]

Tarshis, I.B., and Herman, C.M., 1965, Is *Cnephia invenusta* (Walker) a possible important vector of Leucodytozoon in Canada geese?: Bulletin of the Wildlife Disease Association v. 1, no. 2, p. 10–11.

Vyas, N.B., Spann, J.W., Heinz, G.H., Beyer, W.N., Jaquette, J.A., and Mengelkoch, J.M., 2000, Lead poisoning of passerines at a trap and skeet range: Environmental Pollution, v. 107, no. 1, p. 159–166. [Also available at http://dx.doi.org/10.1016/S0269-7491(99)00112-8.]

Red fox (*Vulpes vulpes*) in pen, Patuxent Research Refuge, Laurel, MD, 1972. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Urban Wildlife Research at Patuxent

Lowell W. Adams

Introduction

Urban wildlife research at Patuxent Wildlife Research Center (Patuxent) has spanned the last 50 years of Patuxent's 80-year history (1936–2016). Urban research dealt with birds, mammals, reptiles, invertebrates, wetlands, stream ecology, contaminants, diseases, and parasites. The U.S. Fish and Wildlife Service (USFWS) officially established an urban wildlife research program in June 1972 (Geis, 1981). The program focused on birds and was headed by Dr. Aelred D. Geis at Patuxent's central campus in Laurel, MD. In this chapter, I present a review of urban wildlife research conducted by Dr. Geis and other investigators at Patuxent's central campus and its various field stations.

Birds

Early research conducted by Dr. Geis dealt with changes in the bird community as the planned development of the town of Columbia, MD, was underway. From 1966 to 1971, he conducted breeding and wintering bird surveys at Town Center and in the Village of Wilde Lake (Geis, 1974a, 1974b, 1976). During the breeding season, the number of birds of species associated with farmland and field habitat declined. Birds in this category included northern bobwhite (*Colinus virginianus*), mourning dove (*Zenaida macroura*), eastern meadowlark (*Sturnella magna*), red-winged blackbird (*Agelaius phoeniceus*), and grasshopper sparrow (*Ammodramus savannarum*). Numbers of wood thrush (*Hylocichla mustelina*) (woodland species) and indigo bunting (*Passerina cyanea*) (edge species) also declined. Birds whose numbers increased during this period included northern mockingbird (*Mimus polyglottos*), chipping sparrow (*Spizella passerina*), song sparrow (*Melospiza melodia*), European starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), and house wren (*Troglodytes aedon*). The number of northern cardinals (*Cardinalis cardinalis*) did not change.

In Columbia, housing type affected species composition and bird density (Geis, 1974a, 1974b, 1976). Detached houses with lots on which some of the original trees had been retained had the most varied species composition. Bird diversity declined in more intensely developed areas characterized by townhouses and apartments. Townhouse and apartment complexes, however, showed the greatest bird density, consisting mostly of house sparrows and European starlings. Geis (1974a, 1974b, 1976) observed that starlings and house sparrows were related to building design and quality of construction. Unboxed eaves provided small openings beneath house roofs that birds used for nesting sites (fig. 1), and widely louvered air vents and latticework used to camouflage air-conditioning units at apartment buildings provided attractive nesting sites for starlings and house sparrows.

Also in Columbia, Geis and his colleagues compared two methods for counting birds in urban areas (DeGraaf and others, 1991)—point counts and transect counts. They reported that transects centered on roads through residential developments and divided into 300- × 300-foot (ft) plots for recording data reduced many of the problems associated with counting birds in urban areas, such as varying noise and visibility.

Figure 1. Bird nest in a house eave, Columbia, MD. Unboxed eaves provided small openings beneath house roofs in which birds could build nests. Photo by Aelred D. Geis, U.S. Fish and Wildlife Service.

Because 80 percent of bird observations were recorded in the first 4 minutes of sampling, they concluded that 4 minutes per plot was a reasonable time limit (DeGraaf and others, 1991).

Geis (1980a) surveyed breeding and wintering birds at Cylburn Park in Baltimore, MD, before construction of adjacent Coldspring Town. The 174-acre park was a natural area containing a large forest tract in an urban setting. Coldspring Town was planned as a high-density residential area (10 dwelling units per acre). In addition to Cylburn Park and predevelopment Coldspring Town, Geis (1980a) surveyed a nearby mature residential area of detached and two-family attached housing with scattered native trees and an abundance of mature shrubbery during 1974–76. Buildings ranged from 25 to 60 years old. Geis (1980a) reported the greatest density of birds and the smallest number of species in the mature residential area. In contrast, the mature forest of Cylburn Park had the lowest density of birds and the largest number of species (33, compared with 22 in the mature residential area).

In the 1970s, Geis addressed questions related to bird feeding. He focused research efforts on the seeds birds liked to eat and, therefore, the most efficient way for people to feed birds. From 1977 to 1979, volunteers recorded more than 179,000 bird visits and food consumption at experimental feeders near their homes (Geis, 1980b; fig. 2). Geis reported that the small oil sunflower seed and white proso millet were preferred by birds under Maryland conditions. The large, black-striped sunflower seed, at the time the traditionally used sunflower seed for feeding birds, also was reported to be preferred. Many seeds in wild bird mixes sold on the market, including wheat, milo, peanut hearts, hulled oats, and rice, however, were generally unattractive to birds. Feeding preferences differed by species. Nevertheless, on the basis of Geis's work, oil sunflower and white proso millet became widely popular seeds for feeding birds. At the time, oil sunflower seeds were not marketed as birdseed. Geis's work created public demand, and he played a role in convincing the seed industry to make oil sunflower seeds available as birdseed. Geis's research report was in high demand by the public and was distributed widely as a USFWS Special Scientific Report (Geis, 1980b).

Patuxent biologists completed some urban bird research before establishment of the urban wildlife research program mentioned above. Linehan and others (1967) reported early results from an ecological study of urban woodlots in Delaware initiated in 1964. These investigators studied birds in nine woodlots during the breeding seasons of 1966 and 1967. Woodlot sizes ranged from 2 to 36 acres. Fifty-three species were recorded. Of 27 species common in the woodlots, only 13 were considered true forest birds. Many were edge species that could make use of the considerable amount of edge habitat associated with the small woodlots. Linehan and others (1967) observed that red-eyed vireo (*Vireo olivaceus*)

Figure 2. Bird-feeding station, Howard County, MD, 1980—one of the sites where birdseed was tested. Photo by Lowell W. Adams, Urban Wildlife Research Center, Columbia, MD.

breeding density was positively related to woodlot size. The red-eyed vireo was 1 of 21 species later identified by Darr and others (1998) and other researchers as an "area-sensitive" species whose probability of occurrence increases with the size of unfragmented forested areas. Of the 21 principal species recorded in the Delaware urban woodlots, only 4—wood thrush, red-eyed vireo, red-bellied woodpecker (*Melanerpes carolinus*), and eastern wood-pewee (*Contopus virens*)—were classified as area sensitive by Darr and others (1998). The small Delaware woodlots lacked woodland warblers and tanagers, along with vireos and other forest interior species that require larger forested tracts to breed and nest successfully. Nevertheless, the Delaware urban woodlots provided habitat for many birds. Linehan and others (1967) concluded, "Very dense populations of a large variety of breeding birds are found in urban woodlots of 20 or more acres which have adequate shrub understory, mature and dead standing trees, and vegetative edge types that are of sufficient width and proper quality." Results of additional work conducted in Delaware urban-suburban woodlots were reported by Jones and others (1966), Longcore and others (1966), and West and others (1966).

Patuxent researchers studied a black-crowned night heron (*Nycticorax nycticorax*) nesting colony in the Patapsco River estuary of Baltimore Harbor, MD, during May–July 1988 (Erwin and others, 1990, 1991). The colony consisted of more than 300 nesting pairs, and researchers were interested in determining whether or not birds avoided using contaminated areas of the urban estuarine environment as feeding sites. Flight directions of birds from the nesting colony were documented, and some birds were followed with aircraft and small boats. More birds appeared to fly west and northwest toward Baltimore than to other areas when leaving the colony on foraging flights, although results were not statistically significant. Areas west and north of the nesting colony were more heavily developed than areas to the east and south. Researchers speculated that city lights might have attracted small fish, crabs, and invertebrates, which, in turn, attracted the herons. Black-crowned night herons that feed in contaminated urban-suburban environments may not as a result experience direct threats to their survival or reproductive success (Rattner and others, 2000), but access to high-quality, uncontaminated wetlands with a large prey base probably could better sustain colonial wading bird populations.

Sparling and others (2007) studied nesting success and foraging behavior of red-winged blackbirds in stormwater wetlands in metropolitan areas. Such wetlands are constructed to manage stormwater runoff from developed sites following rain events. Controlling stormwater is required by law in many jurisdictions. Sparling and his colleagues focused on stormwater retention wetlands draining residential, commercial, and highway sites. These investigators studied birds at 12 stormwater retention wetlands in Prince George's, Howard, and Anne Arundel Counties, MD, during 1993–94. They noted no significant differences in nest success among the wetland types. Number of nests was positively correlated with percent of area occupied by cattail (*Typha* spp.), and nest success and foraging rates were similar to those reported for natural wetlands. Forty-seven species of birds were recorded, and investigators concluded that stormwater wetlands could provide suitable habitat for red-winged blackbirds and perhaps other species. Although constructed for stormwater control, wetland features can be designed to either attract or discourage wildlife use. Such features include size and shape of the wetland, side slope (steep or shallow), water depth, and percent of area occupied by cattails.

Monitoring wetland contaminants, particularly zinc and copper, in stormwater wetlands would provide more information about potential problems with contaminants. In a related study of the same sites, Sparling and others (2004) focused on contaminant exposure of nestling red-winged blackbirds. Investigators reported elevated concentrations of zinc and copper in wetland sediments and carcasses of 8-day-old chicks. Sediment zinc concentrations were negatively correlated with average red-winged blackbird clutch size, hatching success, fledgling success, and nest success. Overall, however, nest success was comparable to national averages. Additional study of this issue could yield important information that could be used to help educate the public about the benefits of controlling sedimentation rates and prevent wetland areas from becoming toxic sinks to wildlife.

Patuxent researchers also have studied the effect of urban light on birds. On the Hawaiian Island of Kauai, more than 1,000 fledgling seabirds of three species were attracted to coastal lights during autumn flights to the ocean (Telfer and others, 1987). All three species are either threatened or endangered. The birds, apparently on their first flight to the ocean, became disoriented and crashed into buildings, wires, vehicles, and other structures. The phenomenon has increased since the early 1960s as urban areas have grown and the number of high-intensity lights has increased. From 1978 to 1985, 11,767 Newell's shearwaters (*Puffinus auricularis newelli*), 38 dark-rumped petrels (*Pterodroma phaeopygia sandwichensis*), and 8 band-rumped storm-petrels (*Oceanodroma castro cryptoleucura*) were found downed—that is, either dead (8.6 percent) or still alive, but injured or stunned on the ground, unable to fly. The anomaly was most severe at river mouths near urban coastal areas. Apparently, young birds followed rivers from inland nesting grounds to the sea and became disoriented because of urban lights along the coast. Through a program established with public cooperation and government-run "aid stations," 90 percent of the downed birds were returned to the wild. Telfer and his colleagues reported that light shielding can reduce the problem, and some resort owners were convinced to turn off some of their decorative lights during the most critical period.

Other researchers at Patuxent described methodologies for reporting bird species richness and community structure. Using Breeding Bird Survey data (Sauer and others, 1997), Cam and others (2000) found significant negative correlations between bird species richness and urban land use in six physiographic regions of the Mid-Atlantic States (fig. 3).

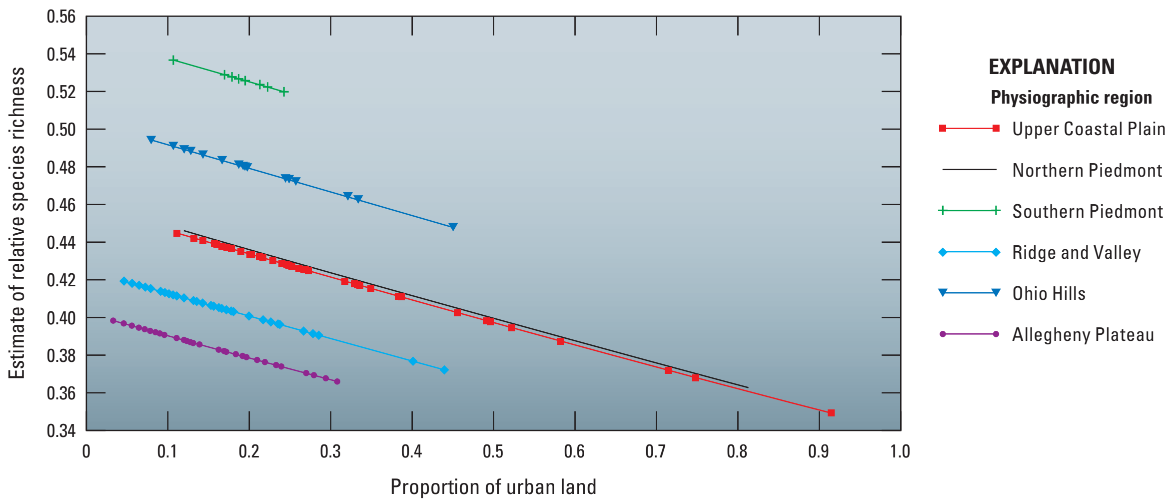


Figure 3. Relation between relative species richness and proportion of urban land (arcsine square-root transformed) by physiographic region. Relations were estimated by using a model. (Modified from Cam and others, 2000)

These investigators pointed out that local species richness may be affected by local and regional factors. They presented a method to estimate relative species richness that accounts for potential variation in species detection probability and allows flexibility in specification of a reference community. For example, it is not likely that all species are detected during sampling sessions. The defined species list ideally is derived from regional data, they noted, and a smaller regional pool might help to account for fewer species at a site.

Research at Patuxent has yielded conclusions about planning for and management of urban and urbanizing areas (Leedy and Geis, 1980; Geis 1986a, 1986b). Geis (1986a) reviewed the early history of the development of the planned community of Columbia, MD. In 1965, county zoning called for a minimum of 20 percent open space, a minimum of 15 percent low-density residential housing, and a maximum of 10 percent attached housing. Zoning was changed in 1973 to require a minimum of 30 percent open space, a minimum of 12 percent low-density residential housing, and a maximum of 12 percent attached housing. Less than a decade later, these regulations were changed again to require a minimum of 36 percent open space and a minimum of 10 percent low-density residential housing. Although these zoning changes were prompted by changes in housing demand, they also had ecological benefits. Geis (1986a) noted that many trees were preserved during development and that many more trees and shrubs were planted following development. In addition, the water areas (three lakes and many ponds) that were created benefited wildlife. These characteristics plus the large amount of open space retained after development were considered positive for wildlife populations. Geis (1986a) noted, however, that originally there was no plan to manage open space. It was simply mowed on a regular basis (fig. 4), providing little wildlife habitat. He suggested that the open space could be managed to enhance both wildlife habitat and public wildlife viewing opportunities. He also noted that building design and construction characteristics in some areas allowed populations of European starlings, house sparrows, and common pigeons (*Columba livia*) to increase, often causing nuisance situations for residents.

Figure 4. Early residential development and open space in Columbia, MD. Geis (1986b) noted that open space could be managed to enhance wildlife habitat and public wildlife viewing opportunities. Photo by Aelred D. Geis, U.S. Fish and Wildlife Service.

Geis (1986b) pointed out that the amount of woody vegetation retained during development and planted after development was the most important factor for the well-being of birds in Columbia. In Europe, he noted, although many areas are intensively manicured near buildings, a hedge is used to separate these areas from less intensively managed areas that are infrequently mowed. He argued that managing open space to include meadow habitat and reduce the amount of regular mowing would provide better habitat that could be beneficial to bird populations.

Obrecht and others (1991) described a 1960 agreement between the USFWS and Potomac Electric Power Company (Washington, D.C.) for managing vegetation on a newly constructed electric transmission line right-of-way through the Patuxent property. A diverse shrub community that was allowed to develop on the right-of-way after construction provided habitat for wildlife. Management consisted of periodic removal of tall-growing tree species to avoid conflict with the overhead electric transmission lines, which was accomplished by selectively applying herbicide to the stems of each unwanted plant. The site effectively showed how right-of-way management can benefit wildlife in metropolitan areas.

Darr and others (1998) used forest breeding bird data in combination with county zoning and a woodland conservation ordinance to develop a forest conservation plan for the watershed of the Western Branch of the Patuxent River in Prince George's County, MD. These investigators were interested in developing a forest conservation plan that would benefit area-sensitive forest breeding birds that require large tracts of forest for successful nesting. Breeding birds were surveyed during the nesting seasons (late May–early July) of 1992 to 1994. Forest tracts were catalogued into seven size classes that ranged from 1.2 to 5 acres to greater than 1,236 acres. Twenty-one of the 100 bird species recorded were determined to be area sensitive. The researchers identified 22 forest tracts of a size that likely would support successfully nesting populations of area-sensitive birds and indicated that giving these areas priority for conservation efforts could have a desirable benefit. They concluded, "The resulting conservation plan will maintain and enhance breeding habitat for area-sensitive forest birds, while still allowing for additional development as human populations increase."

In the southern Piedmont Physiographic Province of the southeastern United States, human population growth was leading to increased conversion of rural, forested, and agricultural lands to urban and suburban areas. Conroy and others (2003) argued that this process leads to loss of "natural capital" in the form of biological diversity and ecosystem function. Although the resilience of ecosystems decreases with increasing human effects on the systems, humans evolved in these ecosystems and are dependent on them for sustaining human life. Conroy and others (2003) suggested that incorporating the concept of ecosystem and landscape resilience into the landscape-level decision-making process could lead to more effective decision making in the future. To incorporate this concept, the economic value of ecosystem services would need to be determined and factored into landscape-level urban and suburban planning.

Mammals

High white-tailed deer (*Odocoileus virginianus*) densities in many metropolitan areas throughout the United States have created human-deer conflict situations (Rudolph and others, 2000). Wildlife researchers have studied nonlethal methods of controlling urban deer density, and Dr. Brian Underwood of Patuxent's field station at the State University of New York College of Environmental Science and Forestry, Syracuse, has been involved with some of that work. He was a member of a team that evaluated immunocontraception for managing suburban white-tailed deer in Irondequoit, NY (a suburb of Rochester). During 1995–98, the team studied efforts required to treat female deer and assessed the utility of using immunocontraception to control growth of the deer population. The researchers reported that the effort to capture and mark deer and to administer follow-up treatment remotely with a dart gun was inversely related to deer density (Rudolph and others, 2000). Some deer were difficult to approach for treatment. Dr. Underwood and his colleagues concluded that the technique had the potential to hold suburban deer populations between 30 and 70 percent of ecological carrying capacity. This technique could be useful in localized populations where treatment involves 100 or fewer deer out of a total population of 200 or fewer animals (Rudolph and others, 2000).

Follow-up research in Irondequoit from 1997 to 2000 focused on using immunocontraception for managing deer on a local scale (2–4 square miles) (Porter and others, 2004). These investigators studied females only and reported that deer showed strong site fidelity. Annual survival was 64 percent, and the major cause of mortality was deer-vehicle collisions. Dispersal rates were less than 15 percent for yearling and adult deer. The study supported the idea of localized, neighborhood-scale management because of high site fidelity, as well as small home-range sizes and limited seasonal movement of the deer.

Reptiles

Ferebee and Henry (2008) studied the movement and distribution of the eastern box turtle (*Terrapene carolina*) in Rock Creek Park, Washington, D.C. The park is surrounded almost entirely by urban development and, at 1,754 acres, is one of the largest national parks in a major city in the United States. These investigators focused their work within a 37.6-acre study area in the northern section of the park during 2001–04. The population density of turtles (2.42–4.02 turtles per acre) was low when compared with that in nearby areas of Patuxent (20.75–22.25 turtles per acre) and Mason Neck National Wildlife Refuge, VA (25.62 turtles per acre). In Rock Creek Park, males outnumbered females 5.3:1. The researchers found no significant evidence of natural recruitment. The old-age structure, low recruitment, low productivity, low population density, removal as pets, and high potential for substantial road mortality, particularly for females, led these investigators to conclude that long-term survival of box turtles in the park was uncertain.

Invertebrates

Aliberti Lubertazzi and Ginsberg (2010) studied dragonfly diversity (Aeshnidae, Corduliidae, Gomphidae, and Libellulidae) at small wetlands along an urbanization gradient in Rhode Island. These investigators reported that diversity, species richness, and evenness did not change along the gradient, although relatively rare species generally were found at the rural end of the gradient.

Wetlands

Wetlands are important habitats for many wildlife species and provide other benefits, including groundwater recharge, flood storage, sediment retention, and water-quality enhancement. Unfortunately, by the mid-1980s in the 48 conterminous States of the United States, urbanization had caused the loss of 22 percent of saltwater wetlands and 6 percent of freshwater wetlands (Guntenspergen and Dunn, 1998). Many wetlands that had not been destroyed were altered and degraded. The distribution of water within the hydrologic cycle typically was altered with land development.

Syphax and Hammerschlag (1995) summarized the first efforts to restore freshwater tidal marshes in the Anacostia River of Washington, D.C. Tidal marshes historically were common along the river, and annual wildrice (*Zizania aquatica L.*) and other wetland plants were abundant. During the 1920s to 1940s, the U.S. Army Corps of Engineers dredged and channeled the Anacostia River from the Potomac River to Bladensburg, MD, to improve navigation. In 1940, the marshes at Kenilworth were dredged.

Reconstruction of 32 acres of emergent wetlands of the old Kenilworth marshes began in October 1992 with the addition of fill material to create a gradient of moist soils and water depth. Tidal channels were cut that approximated the original channels. In May 1993, 16 local native plant species were introduced. Hammerschlag and Krafft (2006) reported on 5 years of post-reconstruction monitoring of the 67-acre Kingman Marsh, one of four reconstructed wetlands of the Anacostia River. Vegetation establishment was initially strong but declined with grazing pressure from resident Canada geese (*Branta canadensis*). By 2004, only two of seven planted species remained. Efforts to control the size of the goose population by nonlethal means were unsuccessful.

A similar effect of resident Canada goose grazing on wetland plants was noted along the tidal marshes of the upper Patuxent River at Jug Bay near Upper Marlboro, MD (Haramis and Kearns, 2007). Through experimental use of fenced exclosures during 1999–2004, these investigators demonstrated striking growth of annual wildrice in areas where geese were denied access. Consequently, a goose reduction plan was implemented by addling eggs to reduce recruitment and opening areas to Maryland's September resident goose-hunting season to reduce population size. Approximately 1,700 geese were harvested during a 4-year period. These actions, along with fencing and planting, resulted in dramatic restoration of annual wildrice and other vegetation along a 6-mile- (mi) long section of the upper Patuxent River.

Stream Ecology

Research ecologist Dr. Mary Freeman, based at Patuxent's field station at the University of Georgia in Athens, was a member of a research team studying effects of urbanization on small streams of the Piedmont Physiographic Province of north-central Georgia near Atlanta. One of the team's first publications focused on habitat quality and fish assemblages along an urbanization gradient (Walters and others, 2005). Field work was conducted during 1999–2000. Fish-species richness and density declined with increased urbanization. Centrachids, largely species of bass and sunfish that were more resistant to disturbance, became dominant, and other species declined or were locally extirpated. The number of endemic species as a group declined with increasing urbanization. The researchers concluded that human disturbance might cause major changes in species composition despite only minor changes in species richness.

Also early in its work, the team investigated the function of riparian forests as stream protection buffers in urban and suburban areas at a relatively small scale (Roy and others, 2005a). The unit of measurement was the "reach scale," a 650-ft length of stream. The researchers studied five small streams during 2001–03. Streams with riparian forest had greater channel width and contained more large woody debris than streams without riparian forest (open streams), which had more algae; contained more tolerant fish and habitat generalists, such as largescale stoneroller (*Campostoma oligolepis*) and southern studfish (*Fundulus stellifer*); and had greater herbivore density and size. Catchment-scale (watershed level) land cover may have important effects on fish communities, and reach-scale studies do not detect catchment-scale effects. Roy and his colleagues concluded that preservation of forested riparian fragments alone may not adequately protect stream ecosystems.

The Georgia research team also investigated effects of hydrologic alterations on stream fish assemblages (Roy and others, 2005b). Three land-cover categories based on degree of ground-surface imperviousness (less than 10 percent, 10–20 percent, and greater than 20 percent), with increasing imperviousness representing increasing urbanization, were studied. Altered stormflows in summer and autumn were related to decreased richness of endemic, cosmopolitan, and sensitive fish species. Hydrologic variables explained 22 to 66 percent of the variation in fish-species richness and abundance. The researchers concluded that use of more porous pavement (for roads and parking lots), rain gardens, and drainage swales would increase infiltration and minimize alteration to stream ecosystems.

Additional research in Georgia documented that stream hydrology and sedimentation affect the ability of riparian forests to maintain healthy stream ecosystems in urban catchments. Roy and others (2006) reported that excessive sedimentation in streams was detrimental to sensitive specialist species, and, where such conditions prevailed, forest cover along the stream would not protect the species. The Cherokee darter (*Etheostoma scotti*), a sensitive species that was on the Federal list of threatened species, was not found in the study streams that exhibited the most stormflow alteration. Maintenance of the Cherokee darter most likely will require management of both stormflow alteration and sedimentation loads (Roy and others, 2006). In the north-central Georgia study area, these processes were driven largely by urbanization in the catchment. Riparian forests were important but were not sufficient to protect streams in highly urbanized catchments. Percent forest cover was important at the 0.6-mi stream-length scale only if urbanization was less than 15 percent of the catchment area (Roy and others, 2007). Forest cover at the reach scale (650 ft of stream length) had no effect on fish assemblages. The most sensitive fish species became rare when the level of impervious cover (as a measure of urbanization) reached 2 percent (Wenger and others, 2008).

Urbanization is accompanied by road construction, and roads can alter stream ecosystems. The design of culverts constructed where roads cross over streams greatly affects fish assemblages. Norman and others (2009) reported that, of the culverts tested, the bottomless box culvert appeared to allow unrestricted movement for benthic and water-column fishes. The three-barrel pipe culvert and the box culvert with a bottom restricted fish movement.

On the basis of their research, the Georgia team reviewed the effectiveness of measures for managing aquatic species as areas are urbanized (Wenger and others, 2010). This information was useful in the development of the Etowah Habitat Conservation Plan (HCP) (Etowah HCP Advisory Committee, 2007) for three federally protected fish species in the area—the Etowah darter (*Etheostoma etowahae*), Cherokee darter (*Etheostoma scotti*), and amber darter (*Percina antesella*). The plan included a management policy to address the effects of stormwater runoff and other stressors, and an adaptive management strategy to incorporate new data over time and to adjust management policies on the basis of the new data. Wenger and others (2010) predicted that use of the HCP offered a high probability of long-term persistence of the three fish species.

Other Patuxent researchers have studied the effects of urbanization on fish communities in coastal New England streams (Coles and others, 2004). These investigators found that cyprinids (minnows) and centrarchids (sunfish) were the dominant taxa. Cyprinid richness decreased with increasing urban development, but no clear urban effect was noted for centrarchids. Contaminant-tolerant species, such as white sucker (*Catostomus commersonii*), blacknose dace (*Rhinichthys atratulus*), and bluegill (*Lepomis macrochirus*), were fairly widespread and indicated no strong association with degree of urban development.

Diseases and Parasites

Louis Locke, a histopathologist at Patuxent, reviewed diseases and parasites of urban wildlife at an urban wildlife symposium in 1973 (Locke, 1974). He discussed diseases affecting only wildlife species, such as pox, trichomoniasis, salmonellosis, canine distemper, and Type C botulism, as well as diseases with public-health implications. Included in the latter category were histoplasmosis, cryptococcasis, rabies, and arboviruses, such as eastern, western, and St. Louis encephalitis.

Patuxent investigators at field stations in New York studied the distribution and abundance of West Nile and eastern equine encephalomyelitis virus vectors (mosquitoes) in Suffolk County in relation to human population density and land-use/land-cover patterns (Rochlin and others, 2008). Land-use/land-cover information was obtained from aerial orthophotographs supplied by Suffolk County (2001). Areas were categorized as residential, natural, barren, or saltwater. The researchers reported that land-use/land-cover information provided more accurate spatial resolution and was more useful than human population density in describing mosquito distribution patterns.

Summary

Patuxent Wildlife Research Center (Patuxent) biologists have contributed to an improved understanding of urban wildlife ecology, conservation, and management. The urban wildlife research program established at Patuxent in 1972 was headed by Dr. Aelred D. Geis. Early in his program, Geis studied the relation between bird habitat factors and development of the new town of Columbia, MD, and documented changes in bird communities as urbanization advanced. He determined that population numbers of farmland and field species, such as northern bobwhite, mourning dove, eastern meadowlark, red-winged blackbird, and grasshopper sparrow, declined, whereas population numbers of other species, such as northern mockingbird, chipping sparrow, song sparrow, European starling, house sparrow, and house wren, increased with development. His results showed that building design and construction features affected the density of so-called nuisance birds such as house sparrows and European starlings. Later, Geis studied supplemental bird feeding by people and found that the small oil sunflower seed and white proso millet were preferred by birds under Maryland conditions. At the time (late 1970s), oil sunflower seeds were not marketed as birdseed. Geis's work created public demand and helped convince the seed industry to make oil sunflower seeds available as birdseed. Additional urban bird-related research by other investigators at Patuxent included work on the effects of habitat fragmentation on area-sensitive species and effects of contaminants and artificial light on birds.

Results of studies by Geis and other Patuxent scientists helped guide planners and managers of urban and urbanizing areas by showing that trees and shrubs preserved or planted in urban open spaces, along riparian areas of streams, and within watersheds are valuable for wildlife. Geis's work in the Columbia study area showed that reduced mowing and increased creation of meadow habitat in urban open space would increase both the availability of wildlife habitat and public wildlife viewing opportunities.

Urban wildlife-related research at Patuxent included investigations of nonlethal methods of controlling white-tailed deer density in metropolitan areas; movement and distribution of the eastern box turtle in Rock Creek Park, Washington, D.C.; dragonfly diversity at small wetlands along an urbanization gradient; and diseases and parasites of urban wildlife. Research efforts also focused on wetland restoration in metropolitan Washington, D.C., and stream ecology in north-central Georgia near the State's expanding capital city of Atlanta. Patuxent's location in the Baltimore-Washington metropolitan area facilitates its continuing study of urban wildlife, as well as potential future collaborations with researchers at nearby universities.

References Cited

Aliberti Lubertazzi, M.A., and Ginsberg, H.S., 2010, Emerging dragonfly diversity at small Rhode Island (U.S.A.) wetlands along an urbanization gradient: Urban Ecosystems, v. 13, no. 4, p. 517–533. [Also available at http://dx.doi.org/10.1007/s11252-010-0133-8.]

Cam, Emmanuelle, Nichols, J.D., Sauer, J.R., Hines, J.E., and Flather, C.H., 2000, Relative species richness and community completeness—Birds and urbanization in the mid-Atlantic states: Ecological Applications, v. 10, no. 4, p. 1196–1210. [Also available at http://dx.doi.org/10.2307/2641026.]

Coles, J.F., Cuffney, T.F., McMahon, Gerard, and Beaulieu, K.M., 2004, The effects of urbanization on the biological, physical, and chemical characteristics of coastal New England streams: U.S. Geological Survey Professional Paper 1695, 47 p. [Also available at http://pubs.usgs.gov/pp/pp1695/.]

Conroy, M.J., Allen, C.R., Peterson, J.T., Pritchard, L.J., and Moore, C.T., 2003, Landscape change in the southern Piedmont—Challenges, solutions, and uncertainty across scales: Conservation Ecology, v. 8, no. 2, p. 3. [Also available at http://www.consecol.org/vol8/iss2/art3.]

Darr, L.J., Dawson, D.K., and Robbins, C.S., 1998, Land-use planning to conserve habitat for area-sensitive forest birds: Urban Ecosystems, v. 2, no. 2, p. 75–84. [Also available at http://dx.doi.org/10.1023/A:1009569329324.]

DeGraaf, R.M., Geis, A.D., and Healy, P.A., 1991, Bird population and habitat surveys in urban areas: Landscape and Urban Planning, v. 21, no. 3, p. 181–188. [Also available at http://dx.doi.org/10.1016/0169-2046(91)90017-G.]

Erwin, R.M., Anders, V.P., and Miles-Iverson, K., 1990, "Industrial strength" herons—The black crowns of Baltimore: Maryland Magazine, v. 22, no. 3, p. 80.

Erwin, R.M., Hatfield, J.S., and Link, W.A., 1991, Social foraging and feeding environment of the black-crowned night heron in an industrialized estuary: Bird Behaviour, v. 9, no. 1–2, p. 94–102. [Also available at http://dx.doi.org/10.3727/015613890791749037.]

Etowah Aquatic Habitat Conservation Plan Steering Committee, 2007, Draft Etowah Aquatic Habitat Conservation Plan: Etowah HCP Advisory Committee. [Also available at http://www.etowahaquatichcp.org.]

Ferebee, K.B., and Henry, P.F.P., 2008, Movements and distribution of *Terrapene carolina* in a large urban area, Rock Creek National Park, Washington, D.C., *in* Mitchell, J.C., Brown, R.E.J., and Bartholomew, Breck, eds., Urban herpetology, Herpetological conservation 3: Salt Lake City, UT, Society for the Study of Amphibians and Reptiles, p. 365–372.

Geis, A.D., 1974a, Effects of urbanization and type of urban development on bird populations, *in* Noyes, J.H., and Progulske, D.R., eds., A symposium on wildlife in an urbanizing environment: Amherst, MA, University of Massachusetts, Cooperative Extension Service, p. 97–105.

Geis, A.D., 1974b, The new town bird quadrille: Natural History, v. 83, no. 6, p. 54–60.

Geis, A.D., 1976, Bird populations in a new town: Atlantic Naturalist, v. 31, no. 4, p. 141–146.

Geis, A.D., 1980a, Breeding and wintering bird populations at Cylburn Park and vicinity before the construction of Coldspring Town, *in* Lynch, J.F., ed., Bird populations—A litmus test of the environment, Proceedings of the Mid-Atlantic Natural History Symposium: Atlantic Naturalist, v. 33, p. 5–8.

Geis, A.D., 1980b, Relative attractiveness of different foods at wild bird feeders: U.S. Fish and Wildlife Service, Special Scientific Report—Wildlife, no. 233, 11 p. [Also available at https://archive.org/details/specialscientifi233unit.]

Geis, A.D., 1981, Management and research opportunities with urban wildlife, *in* Odom, R.R., and Guthrie, J.W., eds., Proceedings of the Nongame and Endangered Wildlife Symposium, August 13–14, 1981: Athens, GA, Georgia Department of Natural Resources, Game and Fish Division, Technical Bulletin WL5.37–40, 179 p.

Geis, A.D., 1986a, Planning and design for wildlife conservation in new residential developments—Columbia, Maryland, *in* Stenberg, K., and Shaw, W.W., eds., Wildlife conservation and new residential developments—Proceedings of a National Symposium on Urban Wildlife: Tucson, AZ, University of Arizona, School of Renewable Natural Resources, p. 67–70.

Geis, A.D., 1986b, Wildlife habitat considerations in Columbia, Maryland and vicinity, *in* Stenberg, K., and Shaw, W.W., eds., Wildlife conservation and new residential developments—Proceedings of a National Symposium on Urban Wildlife: Tucson, AZ, University of Arizona, School of Renewable Natural Resources, p. 97–99.

Guntenspergen, G.R., and Dunn, C.P., 1998, Introduction—Long-term ecological sustainability of wetlands in urbanizing landscapes: Urban Ecosystems, v. 2, no. 4, p. 187–188. [Also available at http://dx.doi.org/10.1023/A:1009589820939.]

Hammerschlag, D., and Krafft, C., 2006, Five years (2000–2004) of post-reconstruction monitoring of freshwater tidal wetlands in the urban Anacostia River, Washington, D.C., USA, *in* Catchments to coast: Brisbane, Queensland, Australian Marine Sciences Association and Society of Wetland Scientists, Australian Marine Sciences Association 44th Annual Conference, and the Society of Wetland Scientists 27th International Conference, book of abstracts, p. 53–54 (abstract).

Haramis, G.M., and Kearns, G.D., 2007, Herbivory by resident geese—The loss and recovery of wild rice along the tidal Patuxent River: Journal of Wildlife Management, v. 71, no. 3, p. 788–794. [Also available at http://dx.doi.org/10.2193/2006-350.]

Jones, R.E., Longcore, J.R., and Linehan, J.T., comp., 1966, Thirtieth breeding-bird census—44. Uneven-aged red maple-tulip poplar forest (urban woodlot): Audubon Field Notes, v. 20, p. 647–648.

Leedy, D.L., and Geis, A.D., 1980, Looking ahead!: Naturopa, no. 36, p. 7–10.

Linehan, J.T., Jones, R.E., and Longcore, J.R., 1967, Breeding-bird populations in Delaware's urban woodlots: Audubon Field Notes, v. 21, no. 6, p. 641–646.

Locke, L.N., 1974, Diseases and parasites in urban wildlife, *in* Noyes, J.H., and Progulske, D.R., eds., A Symposium on wildlife in an urbanizing environment: Amherst, MA, University of Massachusetts, Cooperative Extension Service, p. 111 (abstract).

Longcore, J.R., comp., Jones, R.E., and Linehan, J.T., 1966, Thirtieth breeding-bird census—41. Uneven-aged mixed hardwood forest (urban woodlot): Audubon Field Notes, v. 20, p. 643–645.

Norman, J.R., Hagler, M.M., Freeman, M.C., and Freeman, B.J., 2009, Application of a multistate model to estimate culvert effects on movement of small fishes: Transactions of the American Fisheries Society, v. 138, no. 4, p. 826–838. [Also available at http://dx.doi.org/10.1577/T08-156.1.]

Obrecht, H.H., III, Fleming, W.J., and Parsons, J.H., 1991, Management of powerline rights-of-way for botanical and wildlife value in metropolitan areas, *in* Adams, L.W., and Leedy, D.L., eds., Wildlife conservation in metropolitan environments—National Institute for Urban Wildlife Symposium Series 2: Columbia, MD, National Institute for Urban Wildlife, p. 255.

Porter, W.F., Underwood, H.B., and Woodard, J.L., 2004, Movement behavior, dispersal, and the potential for localized management of deer in a suburban environment: Journal of Wildlife Management, v. 68, no. 2, p. 247–256. [Also available at http://www.jstor.org/stable/3803301.]

Rattner, B.A., Hoffman, D.J., Melancon, M.J., Olsen, G.H., and Schmidt, S.R., 2000, Organochlorine and metal contaminant exposure and effects in hatching black-crowned night herons (*Nycticorax nycticorax*) in Delaware Bay: Archives of Environmental Contamination and Toxicology, v. 39, no. 1, p. 38–45. [Also available at http://link.springer.com/article/10.1007%2Fs002440010077.]

Rochlin, I., Harding, K., Ginsberg, H.S., and Campbell, S.R., 2008, Comparative analysis of distribution and abundance of West Nile and Eastern Equine Encephalomyelitis virus vectors in Suffolk County, New York, using human population density and land use/cover data: Journal of Medical Entomology, v. 45, no. 3, p. 563–571. [Also available at http://www.bioone.org/doi/abs/10.1603/0022-2585%282008%2945[563%3ACAODAA]2.0.CO%3B2.]

Roy, A.H., Faust, C.L., Freeman, M.C., and Meyer, J.L., 2005a, Reach-scale effects of riparian forest cover on urban stream ecosystems: Canadian Journal of Fisheries and Aquatic Sciences, v. 62, no. 10, p. 2312–2329. [Also available at http://dx.doi.org/10.1139/f05-135.]

Roy, A.H., Freeman, B.J., and Freeman, M.C., 2007, Riparian influences on stream fish assemblage structure in urbanizing streams: Landscape Ecology, v. 22, no. 3, p. 385–402. [Also available at http://dx.doi.org/10.1007/s10980-006-9034-x.]

Roy, A.H., Freeman, M.C., Freeman, B.J., Wenger, S.J., Ensign W.E., and Meyer, J.L., 2005b, Investigating hydrologic alteration as a mechanism of fish assemblage shifts in urbanizing streams: Journal of the North American Benthological Society, v. 24, no. 3, p. 656–678. [Also available at http://dx.doi.org/10.1899/04-022.1.]

Roy, A.H., Freeman, M.C., Freeman, B.J., Wenger, S.J., Ensign, W.E., and Meyer, J.L., 2006, Importance of riparian forests in urban catchments contingent on sediment and hydrologic regimes: Environmental Management, v. 37, no. 4, p. 523–539. [Also available at http://dx.doi.org/10.1007/s00267-005-0029-1.]

Rudolph, B.A., Porter, W.F., and Underwood, H.B., 2000, Evaluating immunocontraception for managing suburban white-tailed deer in Irondequoit, New York: Journal of Wildlife Management, v. 64, no. 2, p. 463–473. [Also available at http://dx.doi.org/10.2307/3803244.]

Sauer, J.R., Hines, J.E., Gough, G., Thomas, I., and Peterjohn, B.G., 1997, The North American Breeding Bird Survey results and analysis—1966–1996 (ver. 96.4): Laurel, MD, U.S. Geological Survey, Patuxent Wildlife Research Center, accessed March 25, 2015, at http://www.mbr-pwrc.usgs.gov/bbs/bbs96.html.

Sparling, D.W., Eisemann, J.D., and Kuenzel, Wayne, 2004, Contaminant exposure and effects in red-winged blackbirds inhabiting stormwater retention ponds: Environmental Management, v. 33, no. 5, p. 719–729. [Also available at http://link.springer.com/article/10.1007%2Fs00267-003-0058-6.]

Sparling, D.W., Eisemann, J.D., and Kuenzel, Wayne, 2007, Nesting and foraging behavior of red-winged blackbirds in stormwater wetlands: Urban Ecosystems, v. 10, no. 1, p. 1–15. [Also available at http://dx.doi.org/10.1007/s11252-006-0009-0.]

Syphax, S.W., and Hammerschlag, R.S., 1995, The reconstruction of Kenilworth Marsh, the last tidal marsh in Washington, D.C.: Park Science, v. 15, no. 1, p. 1, 16–19. [Also available at http://www.nature.gov/ParkScience/archive/PDF/ParkScience15%281%29Winter1995.pdf.]

Telfer, T.C., Sincock, J.L., Byrd, G.V., and Reed, J.R., 1987, Attraction of Hawaiian seabirds to lights—Conservation efforts and effects of moon phase: Wildlife Society Bulletin, v. 15, no. 3, p. 406–413. [Also available at http://www.jstor.org/stable/3782548.]

Walters, D.M., Freeman, M.C., Leigh, D.S., Freeman, B.J., and Pringle, C.M., 2005, Urbanization effects on fishes and habitat quality in a southern Piedmont river basin, *in* Brown, L.R., Gray. R.H., Hughes. R.M., and Meador, M.R., eds., Effects of urbanization on stream ecosystems: Bethesda, MD, American Fisheries Society Symposium 47, p. 69–85.

Wenger, S.J., Freeman, M.C., Fowler, L.A., Freeman, B.J., and Peterson, J.T., 2010, Conservation planning for imperiled aquatic species in an urbanizing environment: Landscape and Urban Planning, v. 97, no. 1, p. 11–21. [Also available at http://dx.doi.org/10.1016/j.landurbplan.2010.04.006.]

Wenger, S.J., Peterson, J.T., Freeman, M.C., Freeman, B.J., and Homans, D.D., 2008, Stream fish occurrence in response to impervious cover, historic land use, and hydrogeomorphic factors: Canadian Journal of Fisheries and Aquatic Sciences, v. 65, no. 7, p. 1250–1264. [Also available at http://www.nrcresearchpress.com/doi/abs/10.1139/F08-046#.V1B-BuQR0g4.]

West, R.L., comp., Jones, R.E., Longcore, J.R., and Linehan, J.T., 1966, Thirtieth breeding-bird census—42. Mature tulip poplar forest (suburban woodlot): Audubon Field Notes, v. 20, no. 6, p. 645–646.

Patuxent Research Refuge—Supporting Wildlife Science

Bradley A. Knudsen

Patuxent Research Refuge in Laurel, MD, was established by President Franklin D. Roosevelt through Executive Order 7514, dated December 17, 1936. This Order clearly expressed the purpose of the refuge—"…to effectuate further the purposes of the Migratory Bird Conservation Act… reserved and set apart…as a wildlife experiment and research refuge." Since 1936, Patuxent Research Refuge has amassed a myriad of purposes through various land acquisition authorities or additional Executive Orders—for example, "for use as an inviolate sanctuary, or for any other management purpose, for migratory birds" (16 U.S.C. 715d, Migratory Bird Conservation Act of 1929), and "…recreation, conservation, wildlife preservation, and related scientific and educational activities" (Executive Order 11724, June 27, 1973).

The original research purpose remains the primary purpose of the refuge and is applied to any lands added to the refuge since its initial establishment. This purpose remains unique within the National Wildlife Refuge System. The purpose of many refuges is to provide habitat to benefit migratory birds. Other refuges, such as Horicon National Wildlife Refuge in Wisconsin, have a unique purpose—"to provide habitat for redhead ducks" (http://www.fws.gov/refuge/Horicon/about.html, accessed June 19, 2015). Patuxent Research Refuge's purpose is to support the critical function of wildlife research (http://www.fws.gov/refuge/Patuxent/about.html, accessed June 19, 2015).

Two long-time employees offered interesting perspectives on Patuxent Research Refuge and its ability to provide opportunities for wildlife research. Retired refuge biologist Holliday Obrecht, a scientist for nearly 30 years, often said that the refuge rarely had to turn away a research request because of the variety of habitats the refuge had to offer (Holliday Obrecht, U.S. Fish and Wildlife Service, oral commun., 2012). Retired wildlife research scientist Dr. Chandler Robbins, in a recent video production, "History of Patuxent" (U.S. Geological Survey, 2011), which highlights the history of Patuxent, says, "It was Gabrielson's dream [referring to Dr. Ira Gabrielson, who was instrumental in the establishment of Patuxent Research Refuge] to maintain a variety of habitats to conduct research…" Other speakers who appear on the video include Susan Haseltine, Gary H. Heinz, Kathy O'Malley, Matthew Perry, Chandler Robbins, and Gregory Smith of the U.S. Geological Survey (USGS), and Bradley A. Knudsen and Frank McGilvrey of the U.S. Fish and Wildlife Service (USFWS).

Trends in the quantity and type of research conducted at Patuxent Research Refuge over the years are shown in figure 1 and table 1, respectively. Much of the research, particularly the decades-long research that has been so critical in documenting habitat and wildlife change over time, has, of course, been conducted by employees stationed at Patuxent Research Refuge. The refuge, however, also has provided research opportunities for nonstaff researchers (universities, State agencies, county environmental managers, and others) on this 12,841-acre "outdoor laboratory" for decades. Since 2000, nonstaff research projects have actually outnumbered projects conducted by staff members.

The variety of flora and fauna studied is equally extensive. Birds certainly have been a focal point, but insects, pollinators, reptiles and amphibians, mammals, fish, fungi, and bacteria have all been included in the multitude of research subjects addressed at Patuxent Research Refuge during the past more than 75 years (1940–2016). The disciplines of population modeling, habitat management, endangered species propagation, toxicology, wildlife and human disease transmission, and environmental threats (habitat fragmentation, acid rain, water quality) have all been topics of past and ongoing research at Patuxent Research Refuge.

In What Other Ways Does Patuxent Research Refuge Support Wildlife Research?

- As mentioned above, the refuge encompasses more than 12,800 acres of federally protected land that can be available for research studies, both short- and long-term, essentially for the foreseeable future.
- The refuge provides a secure land base with law enforcement personnel who offer protection and security for the many captive animal colonies housed on the property.

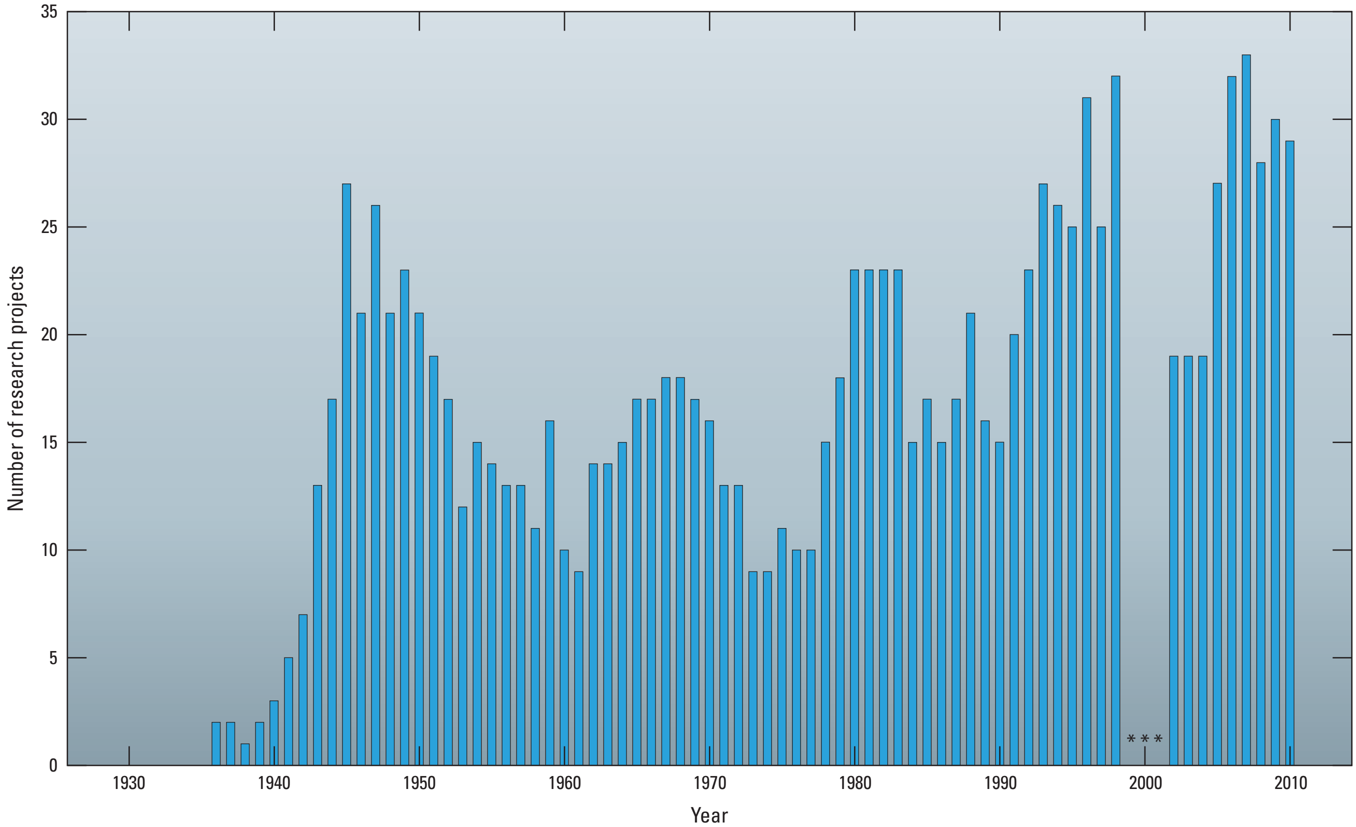


Figure 1. Number of U.S. Fish and Wildlife Service/U.S. Geological Survey research projects conducted by researchers at Patuxent Research Refuge, Laurel, MD, 1936–2010. (*, missing data)

Table 1. Earliest and longest running research at Patuxent Research Refuge, Laurel, MD.

Date	Researcher(s)	Research subject	Reference
		Earliest	
1936–42	Stewart and Robbins	Winter and breeding bird abundance and distribution	Stewart and others, 1952
1936	Hotchkiss and Stewart	Vegetation of Patuxent Research Refuge	Hotchkiss and Stewart, 1947
1936	Armstrong	Fur animal autopsies	None
		Longest running	
70 years	Stewart and Robbins	Christmas bird counts	Robbins, 1966
40 years	Stewart/Henny/Martin	Red-shouldered hawk (*Buteo lineatus*) nest survey and population ecology	Stewart, 1949; Henny and others, 1973; Martin, 2004
40 years	Uhler/McGilvrey/Haramis/Obrecht	Wood duck (*Aix sponsa*) box management and research	Perry and others, 2000
38 years	Stickel/Hall/Henry	Eastern box turtle (*Terrapene carolina*) surveys	Henry, 2003
32 years	Bystrak/Dawson	Mist netting birds for banding	None
30 years	Martin	Butterfly surveys of Central Tract (location of most research study sites; generally closed to the public)	None

- The refuge offers a variety of public uses—hunting, fishing, wildlife observation, environmental education, and interpretation programs— that minimize disturbance to research projects. Its Central Tract, where the bulk of the research is conducted, is closed to public use, except on a few days in the fall when a controlled deer-management hunt is held.
- The National Wildlife Visitor Center in the refuge (fig. 2) is a 40,000-square-foot public facility that presents high-quality exhibits on wildlife research, natural-resource problems, and wildlife conservation. It also offers meeting space for science seminars and workshops for as many as 250 participants.
- The refuge provides office space for the USFWS Division of Migratory Bird Management. Colocation of this group allows for scientific information exchange and collaboration on a variety of wildlife-related needs.
- The refuge supports a large volunteer program of as many as 250 participants annually, many of whom become advocates for the refuge in particular and natural resources in general. Volunteers provide critical support for outreach events and assist with some of the research projects, thereby enhancing and increasing research capability.

Figure 2. Visitor Center facing Lake Redington, Patuxent Research Refuge, Laurel, MD, 1994. Photo by Matthew C. Perry, U.S. Geological Survey.

- Through environmental education and interpretation programs, each year thousands of students are exposed to the wonders of nature and the importance of the outdoors. It is not unreasonable to hope that their participation has helped nurture a conservation ethic in at least some of these young people, and perhaps has inspired some of them to go on in life to become the next Chan Robbins, Ira Gabrielson, or Rachel Carson.

Dedication of the first and largest fishing pier accessible to persons with disabilities at Patuxent Research Refuge, Laurel, MD, 1992 (left to right: Patuxent Director Harold O'Connor, Prince George's County Executive Parris Glendenning, U.S. Representative Steny Hoyer, and Facility Manager Bill Lomax). Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

A Memorandum of Agreement (MOA) between the USFWS and the USGS, signed by the respective directors of these agencies in September 2000, dealt primarily with the shared responsibilities for operations and maintenance of the substantial infrastructure at Patuxent; however, an important part of this MOA addressed the furthering of and recommitment to Patuxent's research purpose. The MOA described the concept of priority research, defined as "…projects… important to DOI [Department of the Interior], the FWS [U.S. Fish and Wildlife Service], the NWRS [National Wildlife Refuge System], and/or State Fish and Game agencies, and… address important management issues/techniques, and species of concern…," and emphasized the importance of conducting such priority research at the Patuxent Research Refuge and the Patuxent Wildlife Research Center located on the refuge.

This commitment ensures that research will continue to be an essential part of the refuge's future and reaffirms the facility's research purpose. Former Patuxent Wildlife Research Center Director Harold J. O'Connor used to say, "Patuxent Wildlife Research Center is the research part of Patuxent Research Refuge" (Harold O'Connor, U.S. Geological Survey, oral commun., 1994). I would add the following companion statement: Although the nature of research may change over time, research on nature will always be timely.

References Cited

Henny, C.J., Schmid, F.C., Martin, E.M., and Hood, L.L., 1973, Territorial behavior, pesticides, and the population ecology of red-shouldered hawks in central Maryland, 1943–1971: Ecology, v. 54, no. 3, p. 545–554. [Also available at http://dx.doi.org/10.2307/1935339.]

Henry, P.F.P., 2003, The eastern box turtle at the Patuxent Wildlife Research Center 1940s to the present—Another view: Experimental Gerontology, v. 38, no. 7, p. 773–776. [Also available at http://dx.doi.org/10.1016/S0531-5565(03)00107-4.]

Hotchkiss, Neil, and Stewart, R.E., 1947, Vegetation of the Patuxent Research Refuge, Maryland: American Midland Naturalist, v. 38, no. 1, p. 1–75. [Also available at http://dx.doi.org/10.2307/2421630.]

Martin, E.M., 2004, Decreases in a population of red-shouldered hawks nesting in central Maryland: Journal of Raptor Research, v. 38, no. 4, p. 312–319. [Also available at https://www.researchgate.net/publication/266297424_Decreases_in_a_population_of_Red-Shouldered_Hawks_nesting_in_central_Maryland.]

Perry, M.C., Kangas, Partick, and Obrecht, H.H., III., 2000, Creating and managing wetland impoundments to provide habitat for aquatic birds, i*n* Comin, F.A., Herrera, J.A., and Ramirez. J., eds., Limnology and aquatic birds monitoring, modelling and management: Universidad Autonoma de Yucatan, International Symposium on Limnology and Aquatic Birds, Monitoring, Modelling, and Management, 2nd, Merida, Mexico, November 24–27, 1997, p. 261–279.

Robbins, C.S., 1966, The Christmas count, *in* Stefferud, Alfred, and Nelson, A.L., eds., Birds in our lives: Washington, D.C., U.S. Fish and Wildlife Service, p. 154–163.

Stewart, R.E., 1949, Ecology of a nesting red-shouldered hawk population: Wilson Bulletin, v. 61, no. 1, p. 26–35.

Stewart, R.E., Cope, J.B., Robbins, C.S., and Brainerd, J.W., 1952, Seasonal distribution of bird populations at the Patuxent Research Refuge: American Midland Naturalist, v. 47, no. 2, p. 257–363. [Also available at http://dx.doi.org/10.2307/2422265.]

U.S. Geological Survey, 2011, History of Patuxent: Boston, MA, Northern Light Productions, U.S. Geological Survey video, 27 minutes, accessed February 28, 2016, at http://www.pwrc.usgs.gov/history/history.cfm.

History of the Library at Patuxent Wildlife Research Center

By Lynda J. Garrett

Patuxent Wildlife Research Center (Patuxent) in Laurel, MD, celebrated its 75th anniversary in 2011. The Patuxent Research Refuge was established in 1936 and, in 1956, it was renamed the Patuxent Wildlife Research Center. The two names have been virtually synonymous throughout the decades since and although three agencies—U.S. Department of Agriculture (USDA), U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey (USGS)—have managed the facility, the refuge and research staffs have acted essentially as one unit (Perry, 2004). The library has supported all the various management and research staffs located at Patuxent since its inception. This chapter recounts primarily the library's history and staffing during the period I was employed there (1969–2013).

The library has been an important part of Patuxent since the establishment of the research facility. I worked in the Patuxent library for more than 43 years, but little information about its early days is available. The USDA library bookplates that can be found in many old volumes from the 1800s in the library hint at some sort of transfer or donation many years ago. Helen P. Alexander was Patuxent's librarian for several years during the 1960s. She left Patuxent in the mid-1960s and later served at the brand-new National Agricultural Library in Beltsville, MD, which opened in 1969.

I applied for a position at Patuxent in February 1969. I was not interested in a career at that time because I expected my husband to be drafted soon. I was told I would need a Civil Service rating to be a candidate for a Federal job, even a clerk-typist position. I went to the Civil Service Commission (now Office of Personnel Management) in Washington, D.C., to take the test. Half of the test was multiple choice; the other half was typing! The only machines available were old manual typewriters. I had not touched one of those in years, so I did not pass the typing test. Thankfully, applicants could repeat that part of the test on another day, and were allowed to bring an electric typewriter. Therefore, I rented a portable electric machine and passed on my second try.

I arrived at my new Federal clerk-typist job in March 1969, and operated the antiquated switchboard in the director's office in the Gabrielson Laboratory building (Gabrielson), as a General Schedule- (GS) 3 employee, for 6 months. Gabrielson, which had just opened in December 1968, was named for Ira N. Gabrielson, the first director of the newly formed USFWS in 1940, who earlier had been influential in the creation of Patuxent Research Refuge in 1936. Evelyn Schoenborn was the director's secretary, and my supervisor.

Ruth Nunnally was the GS-5 library technician, but no librarian position existed at that time. The director, Eugene Dustman, knew that Ruth planned to retire in the summer. He noted that I had listed previous library experience on my application and had me in mind to replace Ruth, which I did, in August 1969, as a GS-4. Ken Chiavetta became my new supervisor.

I had a break in service at Patuxent from July 1970 to November 1971, while my husband served his time in the U.S. Army in Kentucky. When we were ready to return to Maryland, I inquired about whether I might be able to have my old job back. However, Sue Samson was the library technician at that time, having recently arrived at Patuxent with her husband, Fred, who was a biologist. Therefore, I contacted my former supervisor, Ken Chiavetta, who arranged for me to have the job in the Pesticides Library located in the Merriam Laboratory (Merriam). The main duty there was mailing reprint requests on postcards for articles to be filed in the pesticides file cabinets—all 15 of them. That collection is still (2016) located in the basement of Gabrielson, room G10. Sue and Fred moved away in 1972 and, once again, I accepted the library technician position.

The library was on the second floor of Merriam. Initially, most of the library was in the large room that spanned the width of the building at the north end of the hall—room 212—and was very crowded. Migratory bird biologists located in Merriam who were assigned to the newly formed Migratory Bird and Habitat Research Laboratory (MBHRL) were scheduled to move to Gabrielson. After the move, the library was assigned the vacated space and, consequently, was able to expand.

At that time in the 1970s, Patuxent housed two additional library collections. One was located in the Chemistry-Pathology building, later renamed the Stickel Laboratory. The other library collection, housed in Gabrielson, consisted of materials belonging to the Non-Game Bird Section. Chan Robbins, the section chief, and Ceil Nalley, a statistical assistant, looked after the collection. During the 1970s, those holdings served the newly created MBHRL, which disbanded in 1981 when migratory bird research returned to Patuxent.

The Merriam Library was supervised by Ken Chiavetta, the editor of "Wildlife Review." Ferne Maines, a library aide, was also part of the library staff. "Wildlife Review" was a USFWS print quarterly index that was published in Chicago beginning in 1935. Following the retirement of Waldo McAtee, the editor since its inception, in 1948, "Wildlife Review" moved to Patuxent, where it was edited, in turn, by Neil Hotchkiss, Bill Stickel, and Ken Chiavetta. In conjunction with "Wildlife Review" activities, the Patuxent library developed extensive holdings in wildlife literature, and "Wildlife Review" became an invaluable reference for wildlife professionals (Humphrey, 1992). In 1975, both "Wildlife Review" and Ken were transferred to Fort Collins, CO. "Wildlife Review" continued as a print product until 1995, when the National Biological Service discontinued funding the publication because of budget reductions. The database continues today (2016) as a commercially available electronic title offered through subscription by EBSCO Publishing (Ipswich, MA) as "Wildlife and Ecology Studies Worldwide."

In the spring of 1978, I took the Civil Service librarian equivalency exam. My passing score allowed me to move from a library technician position to a librarian position, GS-7. During 1975–83, the library was supervised first by Patuxent's director, Lucille Stickel, and then by William Stickel, a renowned wildlife research biologist. The Stickels both retired in 1983.

In 1983, David Trauger became Patuxent's director and established the Branch of Technical Services. The branch chief was biologist Nancy Coon. The Information Management Section was supervised by biologist Matt Perry, and included the library and manuscript tracking, which was handled by Nancy Bushby, a technical information specialist.

One of Dave Trauger's early decisions was to consolidate all of the Patuxent library's holdings into the Merriam location. He also authorized an extensive remodeling of the library. Work included painting the walls, painting all metal shelving and file cabinets, and installing carpeting and a drop ceiling. New shelving was added to rooms down the second-floor hallway to make room for titles relocated from the Chemistry-Pathology Laboratory and Gabrielson. The remodeling process required moving all library materials at least twice! Kinard Boone, a newly hired technician, did most of the moving each time.

In 1990, under Director Harold O'Connor, the Branch of Technical Services was abolished and its information-transfer functions were moved to the Office of Administrative Services under Joe Nagel. I was disappointed with this change because I believed that organizing the support services as a separate Branch of Technical Services underscored their importance and enhanced their visibility. In 1994, the library was moved again—this time to the second floor of Gabrielson. All of the stacks were in one room, but shelving space was reduced by about 10 percent. The pesticides and pollution collection was relocated to the Gabrielson basement, first to room G2 and, later, to room G10.

In the spring of 1996, just before Joe Nagel resigned, still another reorganization occurred; it placed the library under Information Resources Management (IRM), with Bob Munro supervising Wanda Manning, the library technician, and me. As a result of this reorganization, the library was again aligned with other technical support staff. In 2003, Bob retired and Rodney Payne was hired as the IRM coordinator. Rodney remained in this position until October 2008. Wanda Manning, who had worked at Patuxent since 1989, resigned in 2003.

(Left to right) Dick Coon, Nancy Coon, Matt Perry, and Lynda J. Garrett in front of the current periodical display rack in the Patuxent Wildlife Research Center library, Laurel, MD, 2000. Photo by U.S. Geological Survey.

Various part-time contractors and students followed until 2009. Long-time library volunteer Betty Murphy left in 2010.

I was offered some generous travel opportunities during the years that the Federal Interagency Field Librarians Workshops were held. These workshops were held in Washington, D.C., in even years and in other cities (Denver, CO; Seattle, WA; and New Orleans, LA) in odd years. The training sessions provided during the workshops were valuable, but they were discontinued in 1986. In 1993, I traveled to Tucson, AZ, for museum property training because of a concern in USFWS headquarters that historical government property needed a different type of management.

The library at Patuxent supports research and the publishing of that research. The five functions discussed below—literature searching, interlibrary loan, journal subscriptions, cataloging, and the Patuxent bibliography—constitute the library's support role.

Literature Searching

During most of my working years, computer literature searching was not available to the individual researcher. Librarians at the Department of the Interior Library completed requested literature searches until 1984, when Patuxent acquired an account with Dialog (now [2016] ProQuest Dialog™), which allowed our local Patuxent library personnel to complete precision searches. I ran these searches through the years along with IRM staff members Nancy Bushby and Nancy Hestbeck. By 2001, the Biological Resources Division (BRD) of the USGS began subscribing to "Cambridge Scientific Abstracts" (CSA), which later merged with ProQuest. In 2005, BRD added the research tool Web of Knowledge (now [2016] Web of Science™), which includes BIOSIS® and Zoological Record®. The Web of Knowledge/Web of Science™ research tools enabled all researchers to conduct independent searches. I completed several comprehensive searches to contribute to the preparation of books written by Patuxent staff members.

Interlibrary Loan

Interlibrary loan (ILL) support has always been an important library function. Until 1980, ILL requests were typed on four-part forms and mailed to a library we hoped would own the book or journal. The ILL request process changed dramatically when Patuxent joined Online Computer Library Center, Inc. (OCLC), a worldwide library cooperative, in 1980. OCLC allows requests to be generated online to libraries that are listed as owners of the requested title; in addition, it allows the librarian to request an item from multiple potential lenders, sequentially, using the same request form.

Currently (2016), the Patuxent library staff fills almost twice as many ILL requests for other libraries as we originate ourselves, which reflects the breadth of our library holdings. Records indicate that in fiscal year 1991 (October 1990 through September 1991), we requested 1,162 ILLs for our staff and filled 482 requests from other libraries. In fiscal year 2011 (October 2010 through September 2011), we requested 321 items and filled 488 requests. Filling article requests is faster and more efficient since the installation of a scanner in the photocopy machine. The ability to e-mail the portable document format (pdf) file has simplified the paperwork required and shortened the waiting time for the requesting scientist.

The major reason that we do not place or fill as many requests as we did in the past is the increase in the number of journal titles to which libraries have access online. The USGS Libraries Program subscribes to a comprehensive list of titles that are accessible to all USGS employees—an estimated several thousand unique journal titles in 2011. USGS-wide access to these materials maximizes the equitable availability of information to scientists and eliminates duplicate subscriptions among the various USGS library locations, thereby conserving financial resources.

Through the years, the use of ILLs has greatly contributed to the preparation of a number of books written by Patuxent authors. The successful completion of many of these large projects would have been difficult or perhaps even impossible without easy access to the great variety of literature that has been requested by the library. Patuxent library staff members, in turn, assist other researchers by lending books from the more than 6,000 Patuxent titles offered through the OCLC library utility.

Journal Subscriptions

It was easy to predict that Patuxent's journal subscriptions would change as USGS-wide access to e-journals became more common, reducing the number of subscriptions the library purchases. Many researchers prefer the convenience of desktop access to publications. In 1995, we ordered about 160 print journal titles, whereas for 2011, we ordered just 26 print titles, and the price of some of those "core" titles included online access. Eventually, the list may be reduced to only those titles that do not offer online access. Another result of the availability of e-journals is that we no longer send journals to the bindery—in fact, the government contract binding company that Patuxent used for many years is no longer in operation.

Cataloging

Not long after my title was converted to librarian, I was offered the opportunity to attend a cataloging course in the Library Science program at the University of Maryland. By 1980, when we prepared to join OCLC, Patuxent management decided to use Library of Congress cataloging for our collection and to discontinue the local scheme that was in use at the time. This decision modernized the library and greatly facilitated the day-to-day cataloging of our materials. By 2002, we began offering our catalog online through Reference Manager Web Publisher software.

Patuxent Bibliography

During 1989–2010, the library was the fortunate recipient of the services of a devoted volunteer, Betty Murphy. Her project was to work in the Patuxent author archives, collecting copies of our past publications and placing them in the files in the Gabrielson basement. She also entered the citations into the ProCite (a proprietary commercial reference management software program) database that Nancy Bushby customized for the Patuxent bibliography in the mid-1980s, when Nancy was responsible for tracking manuscripts. This searchable database is currently (2016) available online and can be accessed from the Patuxent Web site (under "Our Products" [http://www.pwrc.usgs.gov/products/]), where many of the citations include the Universal Resource Locator (URL) link to the full text content.

Patuxent's bibliography has been used to populate two other USGS databases. Our citations were uploaded to the USGS Publications Warehouse database in 2009 and, in 2010, I began using our bibliography to update our records in the USGS Information Product Data System (IPDS) report-tracking database. My involvement with the Patuxent bibliography has been one of the most satisfying projects of my career as a librarian.

The years I spent working at the Patuxent library have constituted a wonderful career—far more satisfying than teaching high school history, my first job upon graduating college. It was pure serendipity that caused my curiosity to lead me through the "wildlife" gate on Route 197 in Laurel, MD, in 1969.

References Cited

Perry, M.C., 2004, The evolution of Patuxent as a research refuge and a wildlife research center: Laurel, MD, U.S. Geological Survey, Patuxent Wildlife Research Center, 20 p., accessed November 3, 2011, at http://www.pwrc.usgs.gov/history/cronhist/patuxenthistory_perry.pdf.

Humphrey, J.A., 1992, The history and uses of Wildlife Review and Fisheries Review: Galveston, TX, International Association of Aquatic and Marine Science Libraries and Information Centers, Conference Proceedings, p. 207–213, accessed November 3, 2011, at http://hdl.handle.net/1912/1670.

Dr. Lucille Stickel, U.S. Fish and Wildlife Service, a major supporter of Patuxent Wildlife Research Center library holdings and functions in the 1960s and 1970s. Photo by U.S. Fish and Wildlife Service.

Patuxent's Research Program in an Era of Transitions

James A. Kushlan

Introduction

It was a telephone call to me, not totally unlike that received 9 months earlier by Ron Pulliam (Director of the National Biological Survey [NBS]) from Bruce Babbitt (Secretary of the Interior), which has since entered the lore of United States wildlife conservation history (Pulliam, 1998). The call, in the summer of 1994, bore an offer I never would have imagined being given to me, nor being accepted by me. It differed from Pulliam's job offer experience in that I had indeed applied for the position, albeit solely at the behest of long-time colleagues at the Patuxent Wildlife Research Center (Patuxent) in Laurel, MD. They had been promised an open search for a new director of Patuxent. I had applied to test whether the promise was true.

The NBS director requested on my behalf, and I received, an unprecedented 3-year leave of absence from the University of Mississippi, where I was then chairman of the biology department. Previous appointees to Federal agency positions had received only their allocated 2 years. I was honored to have the offer to lead what in my early professional career was viewed by all as the most important research facility in all of wildlife biology. I wanted to help scientists publish science that was, in fact and in appearance, credible and nonadvocative. This concept had gained traction in recent years (National Academy of Sciences, 1992), and helping to see it through was appealing to me.

I did revel in the possibilities of facilitating expansion of the biological knowledge base available to the Department of Interior (DOI) land-management agencies, especially for migratory birds and even more especially for waterbirds. Therefore, I agreed to undertake what was to be a 3-year tour of duty helping Patuxent during its transition and assisting my colleagues in the process. To be sure, I knew at the time that it would be a difficult, although fascinating, task, and I could proceed boldly dealing with management of a research facility.

Of course, grand plans rarely work out as anticipated. It turned out that the Patuxent at which I arrived in the fall of 1995 had been shorn of its field stations and renamed Patuxent Environmental Science Center (Perry, 2004). Its budget was to be cut $1.5 million and, to accommodate this reduction in funding, one option was to reduce the staff by about two dozen people and eliminate functionality. In October 1996, Patuxent's remaining functions were transferred to the U.S. Geological Survey (USGS). This chapter describes the story of that transitional period at Patuxent: transitions in form, function, structure, aspirations; transitions in the trajectory of many professional careers; and transitions in agencies, including the U.S. Fish and Wildlife Service (USFWS), NBS, National Biological Service, and USGS, and their differing perspectives. It also is the beginning of the story of the future of biological science in the DOI, a tale that as of this writing more than two decades later (2016) has yet to completely unfold.

A History of Agency Roulette

It is generally acknowledged that wildlife studies came into the Federal government in 1885 with the establishment of a Section of Economic Ornithology within the Division of Entomology at the Department of Agriculture (USDA) (Allen, 1954). Its early focus, as that organizational hierarchy indicates, was on the negative and positive relations between birds and agriculture. What birds were there, where, when, and what did they eat? In 1896, the group became the Biological Survey and, under President Theodore Roosevelt's patronage, the Bureau of Biological Survey (Bureau) in 1905. President Roosevelt was one of the great naturalists of his era, an observant amateur ornithologist, and a widely accepted scientific mammalogist (Kushlan, 2011). Roosevelt admired the USGS and he wanted a biological equivalent. Under Roosevelt's direct influence, the Bureau added mammals to its emphasis, along with the new natural history museums and zoos (Matthiessen, 1959). The Bureau also delved into bird and mammal taxonomy and distribution, and their status and trends. The enforcement of the 1900 Lacey Act, which prohibited the interstate transfer of birds killed in violation of State laws, also became their responsibility. The identity, name, and function of the Bureau had lasted a long time—35 years—when a merger with the Bureau of Fisheries of the Department of Commerce produced the USFWS, all in the DOI. It was during this period, in part to address the habitat destruction that characterized the Dustbowl Era, that scientific wildlife management began in earnest, focusing first on waterfowl and fishery stocks (Matthiessen, 1959).

The wildlife research function known as Patuxent took life on December 16, 1936, when President Franklin D.

Roosevelt signed Executive Order 7514, transferring land along the Patuxent River in Maryland to the USDA and authorizing it to be used as a research refuge, essentially a wildlife experiment station equivalent to the nearby agricultural experiment station, in support of the Migratory Bird and Conservation Act (Perry, 2016). The Patuxent Research Refuge was officially dedicated on June 3, 1939, and moved from the USDA to DOI with the USFWS. As habitat was the principal research question of the time, much of the work over the next decades centered on the land base of the experiment station, including its fields, woodlots, and constructed wetlands. From the time the first director, Arnold Nelson, was appointed, the research and the land were under common management.

With the reorganization of the USFWS in 1956, the Patuxent Research Refuge was administratively renamed the Patuxent Wildlife Research Center. Over the decades, Federal wildlife research needs broadened gradually from habitat to such issues as harvest management, and then further to population dynamics, pesticides, endangered and declining species, and nongame birds. With this expansion of need, Patuxent grew in mission, staffing, physical plant, and geographic reach, becoming the largest and arguably the most famous wildlife research laboratory in the world (Perry, 2016).

By the early 1980s, an increasingly complex array of research activities derived from multiple sources was administratively reorganized into disciplines within a centralized structure made to conform to modern management principles. In the late 1980s and early 1990s, Patuxent management explicitly chose to add roles of public use and outreach to its science core (Ballard, 1989) as the Laurel (MD) campus was expanded by incremental increases of land from adjacent Federal agencies and by the building of the National Wildlife Visitor Center, which was funded to highlight the USFWS research history. These role expansions and facility transactions altered both the function and the funding of Patuxent in fundamental ways. Patuxent had always been run on funds appropriated to the USFWS for the research region (Region 8 in Washington, D.C.), and had always been managed solely as a research facility (Perry, 2004).

With increased public use and new facilities and lands to manage, these core funds by necessity were increasingly used to pay for nonresearch matters. Finally, in 1992, additional funds were appropriated to the USFWS Northeast regional office for Patuxent, a refuge manager was appointed to serve under the director, and plans were underway to divide responsibilities between the refuge managers of the region and Patuxent, with Patuxent retaining management control of the historical core of the land and the refuge system taking over the rest (Perry, 2004). This plan did not materialize. At its peak, Patuxent was an institutional juggernaut. It comprised more than 200, mostly scientific staff members; 11 field stations; a $20 million budget; and 12,800 acres of land and facilities (Perry, 2004).

On Earth Day, April, 21, 1993, President Clinton announced his intention to undertake a biological survey of the Nation. This announcement, a single sentence in his speech (http://www.presidency.ucsb.edu/ws/?pid=46460, accessed July 30, 2015), articulated the vision of his Secretary of the Interior, Bruce Babbitt, who, like Roosevelt, was an admirer of the USGS in his youth, wanted a biological equivalent of the USGS, wanted an agency where science was independent of the land-management bureaus, and wanted enhanced capacity to provide the inventories and scientific studies the agencies needed. His rationale was to get ahead of oncoming environmental crises (Stone, 1993).

The new bureau was to be formed by extracting the research functions and staff from the other DOI agencies. It was organized within the 1994 budget process accompanied by the passage of authorizing legislation in the House of Representatives, but not in the Senate, leaving the agency as administratively and budgetarily authorized, but not organically established. But, carrying the vision on, Secretary Babbitt signed an order (Secretarial Order 3165) on May 17, 1993, announcing his intention to create the new bureau and setting that process in motion. On August 20, 1993, letters were mailed transferring personnel with their functions as of passage and signing of the fiscal year (FY) 1994 budget beginning October 1993.

Among other science functions transferred to the NBS were other DOI research centers (some historically spawned by Patuxent), Cooperative Research units at land-grant universities, and research scientists from the National Park Service (NPS) and other bureaus. Also among functions and personnel transferred to the NBS were several from the USFWS Migratory Bird Management Office such as the Bird Banding Laboratory, Breeding Bird Survey, and other inventory activities; the NPS's Center for Urban Ecology; the USFWS Biological Survey Group housed at the National Museum of Natural History; NPS Cooperative Parks Studies Units at universities; and park-based research scientists.

In June 1994, University of Georgia professor Ronald Pulliam became director of the NBS and took over forming his agency. It was to be academic, scientific, independent, unbiased, peer reviewed, and agency responsive, and to address more than wildlife. It would additionally be about ecosystems and technology and tend to big questions of ecology and resource management (Stone, 1993). On January 5, 1995, Secretary Babbitt (Secretarial Order 3185) changed the agency's name to National Biological Service and clarified that its primary role was to meet the biological research needs of the DOI. The agency was short-lived.

A new Congress elected under House of Representatives Speaker Newt Gingrich's leadership took office in January 1995. His "Contract with America" had formally promised to abolish the NBS (Pulliam, 1998a). In 1996, the functions and employees of the NBS became part of the Biological Resources Division of the USGS (Pulliam, 1998b). Additional transitions were in store for everyone. Patuxent's identity, form, and functions underwent substantial changes during this period (Perry, 2004).

Identity

Name changes quickly became an issue. What had been for decades Patuxent Wildlife Research Center was renamed, as of May 10, 1994, Patuxent Environmental Science Center. By the time of my arrival in 1995, the decision had long since been made to change Patuxent's name (Perry, 2004). Among my first assignments was to call on Maryland Senator Paul Sarbanes, who wanted Patuxent's original name reinstated (Perry, 2004). The order came out a few days later, and at Patuxent we had a celebration to enjoy our name restitution. A name change did not change anything fundamentally, but was psychologically uplifting.

With a new logo featuring the bald eagle (*Haliaeetus leucocephalus*), the identity of Patuxent had returned to its roots. When moved to the USGS, it officially became "USGS Patuxent Wildlife Research Center," but it always remained for most just "Patuxent." Of course, outside the wildlife community, "Patuxent" is a Naval air station, a prison, or a Maryland river. Within the wildlife community, it remained one of the centers of its science.

Form

The form I found at Patuxent in 1995 was in my view entirely logical in that its three main disciplinary functions, each with its independent history, were divided among three branches for migratory birds, contaminants, and endangered species. Each had a mid-level manager, who controlled the branch budget and supervision, and each had an administrative staff. Scientists were further divided into groups, each with a supervisor. The form of Patuxent consisted of a centralized command structure, based on the concept of Total Quality Management (TQM) (https://en.wikipedia.org/wiki/Total_quality_management, accessed July 30, 2015) enacted by a Quality Council that met long and regularly. When I first entered Patuxent's conference room, on the wall was a sign assuring the staff that TQM meant that whatever was said in this room by the Quality Team members of TQM stayed in this room and that employees could express their opinions without fear of retribution.

The potential imposition on creativity of TQM in a research environment worried me, and after a couple of months of consideration, I terminated TQM and the three-branch structure. Instead, all the research scientists were to report to one chief scientist and were encouraged to self-organize into recognized, but nonsupervisory, teams around projects, themes, or fields of work as they chose. This was an academic department model. It also eliminated the overhead costs of two layers of management. Finally, the concept of base funding branches was ended in favor of funding on a project basis supported by peer-reviewed proposals that competed for available base funds.

Scientists found freedom to do the work they chose, staying within the overall mission of servicing DOI, so long as they could competitively or by partnership acquire funds for their work and publish it in peer-reviewed journals. USGS headquarters was behaving somewhat similarly, offering funds derived from proposal-driven competition within the agency, and Patuxent scientists did well in this competition. Therefore, all Patuxent research became derived from internal or external peer-reviewed proposals.

Function

The NBS on its creation immediately became regionalized, with Patuxent reporting not to DOI headquarters in Washington, D.C., as it had for 60 years, but to a regional office in West Virginia. Implicit in this regionalization was that Patuxent was no longer to be a national laboratory, but a regional one. Patuxent was stripped of its far-flung field stations, and now consisted of the Laurel campus, including the National Wildlife Visitor Center; staff in Maine; the research and curatorial staff assigned to the U.S. National Museum (taken from the Denver Research Center); and the Center for Urban Ecology (taken from the NPS). The Smithsonian-based scientists were the taxonomic, curatorial, and distributional experts from the USFWS. These acquisitions brought taxonomists, mammalogists, herpetologists, botanists, urban ecologists, and wetland scientists to Patuxent.

The new agency's initial functional areas and budget categories were to be species biology, population dynamics, ecosystems, inventory and monitoring, and technology development and transfer (Stone, 1993). Species biology, population dynamics, and monitoring were within Patuxent's capabilities; ecosystems were not, even though this was clearly to be a principal focus for the new agency. Clearly in the new agency's organization, the initial intention was for Patuxent to have an eastern focus (Perry, 2004). Patuxent did wildlife research on a national, and sometimes international, scope for the entirety of the USFWS. Hal O'Connor and Dave Trauger (respectively, Director and Deputy Director of Patuxent) had gone through a strategic planning process, finished in October 1993, to attempt to align Patuxent more closely with the mandates of its new bureau and to face up to its new realities (Patuxent Wildlife Research Center Quality Council, 1993).

Within the NBS mission elements of species and population dynamics research, Patuxent was able to see the disciplines that had made it famous. National programs continued with contaminants and endangered species. Migratory birds research was clearly to be as much in the future of Patuxent as it was in the past. In the transition, the NBS failed to accumulate all of the USFWS migratory bird science capability, and Patuxent had received no new migratory bird personnel and even lost some from its former field stations to other regions; still, this was Patuxent's strength and a logical growth area.

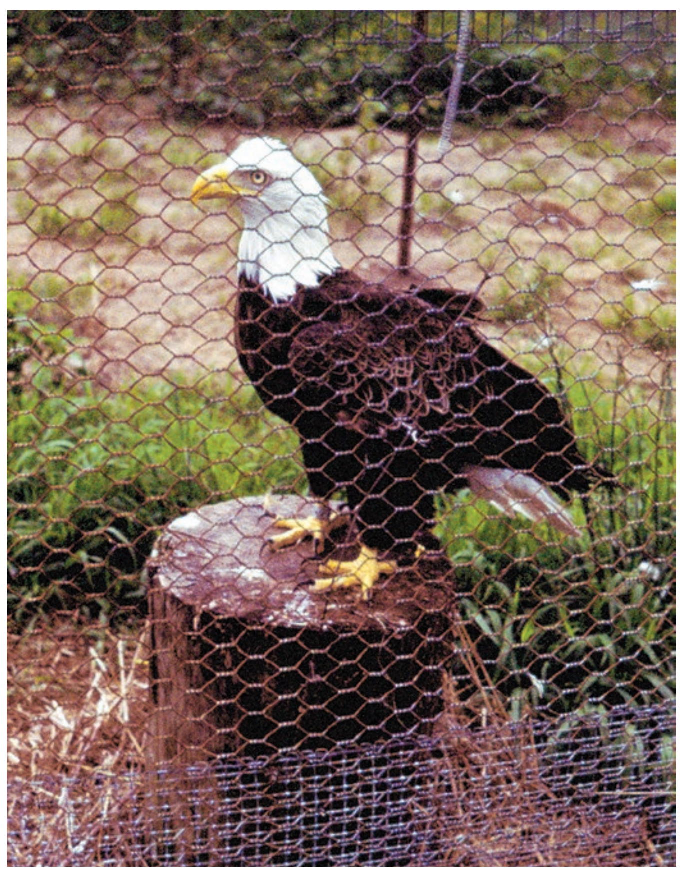
Given that developing geographic information system capabilities and ecosystem- and landscape-scale biological conservation was a fast-moving field for wildlife research, thinness of staff was indeed worrisome. Something needed to be done there. It is worthwhile, therefore, to examine Patuxent's science capabilities at the beginning of NBS.

Endangered Species

Patuxent was long the national leader in terrestrial vertebrate endangered species research, starting in 1965. It was a leader after the passage of the first Endangered Species Act, ready to support the new Federal role in biodiversity conservation, under the leadership of Dr. Ray Erickson (see the "Endangered Species" section of this report). It did the seminal species, reintroduction, and contaminant research on the bald eagle (*Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), brown pelican (*Pelecanus occidentalis*), California condor (*Gymnogyps californianus*), masked bobwhite (*Colinus virginianus ridgwayi*), Puerto Rican parrot (*Amazona vittata*), whooping crane (*Grus americana*), Mississippi sandhill crane (*Grus canadensis*), gray wolf (*Canis lupus*), and black-footed ferret (*Mustela nigripes*). By 1995, much of this reintroduction work had passed operationally to management agencies. Patuxent's one remaining program in the endangered species branch was on cranes.

The crane program had persisted, and the issue of cranes was front and center in the National Biological Service continuing in the Biological Resources Division of the USGS. I impaneled a peer-review team (Scott and Sparrowe, 1999), which agreed that the program should be confined to research; defined the research needed as being studies on reintroduction, not husbandry; and called for maintaining the captive stock needed for this research. An implementation plan for a reintroduction program was developed on the basis of peer-reviewed proposals and, to support this work, no birds were moved. Thus, the whooping crane propagation at Patuxent survived unabated. Patuxent itself had neither the money nor the mandate to lead the reintroduction program, but encouraged partners to do so. In addition to the crane program, Dave Mech's long-term wolf study for a time was returned to Patuxent, and Jeff Spendelow in the migratory bird program studied roseate terns (*Sterna dougallii*).

CANUS (for Canada and the United States), the first whooping crane of many in the captive colony at the Patuxent Wildlife Research Center, Laurel, MD, 1991. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.



Captive bald eagle at Patuxent Wildlife Research Center, Laurel, MD, 1979. Photo by Matthew C. Perry, U.S. Fish and Wildlife Service.

Immature roseate tern (*Sterna dougallii*) color banded for monitoring, Chatham, MA, 2011. Photo by David Monticelli, Marine and Evironmental Sciences Centre, Universidade de Coimbra, Portugal.

Contaminants

Patuxent was once the national leader in wildlife contaminant research, which had started in the mid-1940s. Under Director Lucille Stickel's leadership, Patuxent was able to benefit from attention to pesticides after Rachel Carson published "Silent Spring" in 1962 (Carson, 1962) to build a program that soon had continent-wide implications. By 1995, the program was still producing a substantial number of publications on contaminant effects on wildlife. Much of this work dealt with detailing the questions; summarizing and synthesizing the data; and attempting to address the then-current, but technically difficult, issue of secondary and generational effects by using Patuxent's remaining captive colonies of American kestrels (*Falco sparverius*) and Eastern screech owls (*Megascops asio*).

In the transition to the NBS, the Analytical Control Facility established in 1985 and housed at Patuxent (Perry, 2004) remained with the USFWS, with the rationale that this facility was a scientific service, not research. One functional result was that Patuxent lost its research chemists. Nonetheless, in 1995 Patuxent housed a cadre of contaminant biologists. As demand for their expertise decreased, they documented the continuing progress of environmental regulation. This work continued in the 1990s and thereafter, with special attention to Chesapeake Bay.

Migratory Birds

Patuxent in its largest sense (that is, including entities at the Laurel site not necessarily administered by Patuxent) in 1995 was still one of the world leaders in migratory bird studies. The bureaucratic history is convoluted, as several Federal migratory bird science entities over the previous decades had been established, merged, disestablished, or remerged (Erwin and Blohm, 2016). But over the years prior to the agency transition, migratory bird functions had been rearranged a couple of times, with some eventually becoming part of Patuxent and some remaining in the offices dealing with migratory bird management and habitat. Upon the emergence of the NBS, some of these functions, including the Bird Banding Laboratory (BBL), Breeding Bird Survey (BBS), and similar functions, were transferred, but were managed by headquarters, leaving part of the migratory bird capabilities in the USFWS, part in Patuxent, and part reporting to NBS headquarters, but nearly all colocated at the Laurel site. Thus, the core of the former and present USFWS migratory bird research and migratory bird management functions still resided physically at Laurel by 1995.

After the transition, it became clear to me that Patuxent could seek out this role to amalgamate all the former USFWS migratory bird science functions within the NBS. So a campaign was launched by others and me to secure transfer of at least the BBL and BBS from headquarters to Patuxent. I believed it to be a scientifically and logistically feasible proposition. This proposal was agreed to, with much credit going to USGS Chief Biologist Sue Haseltine, and these programs, along with personnel from the Office of Inventory and Monitoring, were transferred to Patuxent management. Patuxent then sheltered the most important of DOI's long-term bird monitoring programs, which were always considered to have been part of Patuxent in any case (Robbins, 2016; Tautin, 2016). The BBS, started by Chandler Robbins, had always physically resided at Patuxent. The BBL and the Electronic Data Processing center had resided at the Laurel site since 1942. These national responsibilities for bird monitoring were accommodated at Patuxent by erecting for the Monitoring Program a second supervisory section coequal with Research.

It was apparent to nearly all that the functionalities of the BBL were seriously out of date, relying on paper data forms; proprietary and idiosyncratic computer programs; severe and sometimes unfathomable restrictions on awarding banding permits; tight, centralized, person-mediated quality control of data input; and limited and highly controlled data availability. The BBL had long focused on waterfowl harvest, but, clearly, the BBL was a critical adjunct to ornithological research and many levels of resource management. Innovative programs for monitoring bird demography, color banding, and satellite telemetry were being initiated. To address these changes in the scientific community and to settle the BBL in its new bureaucratic home, a peer-review panel was commissioned prior to my arrival, although its report was not published until 1998 (Buckley and others, 1998). Upon its completion, I impaneled an implementation committee that included personnel from the USFWS, conservation organizations, and academia. Under the leadership of John Tautin, slowly but surely, the BBL was "reengineered" and brought into the electronic and communication age (Tautin, 2008, 2016). The process led to developments such as having Federal prisoners make bands, encouraging recoveries by telephone, and attempting to make programs more user friendly. Eventually, the data-processing unit was, for efficiency, merged with Patuxent's other information functions and the BBL became essentially all electronic, relying on the World Wide Web for its functionality.

Similarly, I impaneled a review team led by Raymond O'Connor (University of Maine, Orono) to review the operation of the BBS (O'Connor and others, 2000). Its conclusions were the well-accepted consensus opinions about what might be done better. The BBS was designed in the days of paper field notebooks, and wildlife biologist Bruce Peterjohn had already led it into the electronic era, long before the BBL was able to do so. An implementation plan that followed up on the recommendations was put into action as funding allowed.

Monitoring

Given my emphasis on research independence and eliminating middle management, the observant reader might ask why there was a Monitoring Division separate from the Research Division. The reason for the internal organization within Patuxent was twofold. The activities of the Monitoring Division, although scientific, were not necessarily research functions, and the biologists were not research scientists, but focused on customer service. The new Monitoring Division arrangement soon expanded to encompass colonial waterbird, amphibians, and pollinator monitoring programs, with Patuxent serving as the operational and data hub.

A "downside" of the separation of function was that a recognizable research/nonresearch divide came to exist within the science of Patuxent between publishing research scientists and database-managing scientists. The migratory bird data-managing scientists became increasingly separated, organizationally and intellectually, from the migratory bird research scientists. The migratory bird programs were eventually successfully coalesced by my successor, Dr. Judd A. Howell, under a single supervisory unit. After many years, Federal migratory bird science had achieved a unified home.

Patuxent Wildlife Research Center biologist Sam Droege monitoring bees with a sampling net, 2005. Photo by U.S. Geological Survey.

Reexpansion

With the loss of its distant field stations, scientific personnel, and geographic scope in the mid-1990s, Patuxent had contracted in multiple ways. Accumulation of monitoring programs increased personnel, expanded the program, and reestablished a national scope of work. But Patuxent could have benefited from employing additional scientists, especially because it initially lacked expertise in subject areas important to the National Biological Service, and later to the USGS—especially ecosystems; landscape ecology; climate change; and similar big-question, nonbird issues. Some of this expertise could be gathered as positions became available, and a plan to guide future disciplinary hires was created.

A campaign was launched by Patuxent management staff to recruit these scientists to Patuxent, whose history, administrative expertise, and prestige were positive arguments. In the end, Patuxent accumulated, in addition to the National Museum scientists and its Maine bird-focused field station, the NPS research units at the Universities of Rhode Island, Boston, and Syracuse, incorporating a wide range of park science positions including coastal geology and entomology; the NPS-derived visitor impact research program at Virginia Polytechnic Institute and State University; the world-famous wolf research program located in Minnesota; the contaminant and bird, and, later, freshwater researchers at the University of Georgia (Director Pulliam's home institution); and the bird research station with the multiagency partnership of the Lower Mississippi Joint Venture in Mississippi. As job openings and opportunities became available, positions were filled in the areas of migratory birds, monitoring, bird conservation planning, urban ecology, landscape ecology, and population dynamics, and in the reamalgamation of a wetland ecology/landscape/climate-change group that originally had coalesced at the wetlands center in Lafayette, LA, under the leadership of Dr. Robert Stewart.

In tight economic times, the perceived need and willingness for partnerships can increase. Patuxent had retained its solid relations with national wildlife refuges in the mid-Atlantic and Northeast and, owing to the addition of the Rhode Island unit, gained new connections with national parks in the Northeast. Buoyed by the long-term cooperation among refuges and parks, studies continued in these areas. Patuxent had multifaceted and positive relations with the migratory bird leadership and scientists in the USFWS, especially under the leadership of Paul Schmidt, Dave Smith, and Jon Anderson in Washington, D.C. Combined programs, joint committees, the North American Waterbird Conservation Initiative, cooperative policy setting for the BBL and BBS, parallel migratory bird science directions, and administrative issues were all collectively managed.

Patuxent continued and expanded its involvement with Chesapeake Bay by establishing relations with the leadership of the U.S. Environmental Protection Agency-managed Chesapeake Bay Program, the USFWS Chesapeake field office, the University of Maryland research campuses on the Eastern Shore and Solomon Island, the Smithsonian Environmental Research Center, and the Eastern Shore wildlife refuges. Scientists were engaged in species, restoration, wetland, and contaminant research over much of Chesapeake Bay and its watershed. Patuxent had acquired the science component of the Lower Mississippi Joint Venture, which was then under the leadership of Charles Baxter. It also engaged with the Atlantic Joint Venture, offering space for its science staff. It brought to Patuxent science staff of the USDA Natural Resources Conservation Service, with which I had worked in Mississippi. Patuxent had alumni in Cooperative Research Units at several universities, so these collaborations continued. The USGS State Water Science Centers were seen as potential collaborators, and several staff colocations occurred. Following the NPS example, Patuxent began to establish its scientists at various research universities, as it was clear that Patuxent-university partnerships were to be extremely valuable by increasing productivity.

Partnerships overall were generally beneficial, as they multiplied resources and encouraged scientific interchange. Partnerships can be difficult in practice, however, as institutions are sometimes in competition. In my opinion, partnerships worked best when they were forged by the scientists themselves; however, the partnership effort at the leadership level proved useful during the early period of reintroduction and trust building among entities, as it appeared to reduce impediments for scientists when they chose their collaborations.

Staff and functional acquisitions, targeted hiring, outplacements, and partnerships allowed Patuxent to reexpand. Eventually, staff was located at the Smithsonian Institution and seven universities as well as water-resource and environmental service offices in addition to the Laurel facility. By 2001, Patuxent encompassed 150 positions at 13 locations from Maine to Georgia, with a substantially broadened disciplinary scope. Patuxent's science purview had been reestablished, with both regional strengths and national programs.

Bird Conservation

Given its history, prior reputation, staff expertise, accumulation of well-respected bird biologists throughout the East, and responsibility for national bird databases, Patuxent was in a position to participate in and affect the bird conservation movement, and participated in conservation planning and other wildlife organizational structures with all of these nongovernmental organizations. Patuxent had for decades been an active participant in the Black Duck Joint Venture. It sponsored the organizational meeting for a Sea Duck Joint Venture. It had a field station in the "hot spot" of migratory bird land management thought and practice in Mississippi. After the alternatives had been analyzed, the BBS, established by Chan Robbins, turned out in my opinion to be the best way of estimating status and trends of North American migrant birds. The BBS bird point-count data have been digitized and archived (Robbins, 2016); Chan also undertook to digitize the Audubon Breeding Bird Censuses (Robbins, 1977). Patuxent recreated the colonial waterbird colony database (Erwin and Blohm, 2016), which it had first set in motion in the 1970s. Complementing and working with Partners in Flight and the U.S. Shorebird Plan, Patuxent took the lead in developing the North American Waterbird Conservation Plan (Kushlan and others, 2002). As these planning efforts came to fruition, Patuxent found itself a key player in the development of a continent-wide approach to bird conservation, crystallized in the public-private partnership of the North American Bird Conservation Alliance (Yaich and others, 2000). Patuxent scientists were active participants in the important scientific discussions about the North American Bird Conservation Initiative (NABCI), especially population status and trends and monitoring, and eventually in the state of the bird reports.

Funding

The story of any Federal entity is tied to the story of its funding. Patuxent's funding during the period discussed in this chapter is shown in figure 1.

The reduction in funding from FY 1995 to FY 1996 included the loss of more than half of Patuxent's base funding. Instructions for dealing with this reduction were threefold: The Center for Urban Ecology was to be closed, half of the facilities funding was withdrawn, and employees needed to be terminated (which was called a reduction in force). With this decision, much of the urban planning and park science capabilities used by the NPS that had recently accrued to Patuxent was lost.

The loss of facilities support can be understood from the immediate prior history of Patuxent, when its management emphasis had shifted from pure research to, in addition, accumulating lands, building a Visitor Center, public use, and outreach. Apart from directed appropriations for construction, which indeed covered most of the costs, funding for management of the Visitor Center and of the lands of Patuxent came from the USFWS research budget, which was arguably viewed by some as decreasing the money available for research.

The rest of the decision making was left to Patuxent. Because the funds available for salary were insufficient to support the existing staff, I had to let some employees go. I made the decision to protect the research at all costs; therefore, no cuts and no reduction in force occurred for research and immediate research support positions (other than the Center for Urban Ecology). The rest of Patuxent took a substantial functional blow as facility, administrative, and other support staff positions were eliminated. Managing the force reduction required all of my available personal and professional skills. The result was that 26 people were fired, and, overall, 35 positions were vacated. These actions inevitably had adverse consequences for both morale and functionality at Patuxent. In any organization, recovery from such a mass firing can require a professional generation. The reduction in force was perhaps especially devastating for a Federal workforce for whom job loss was not in their history.

The FY 1996 and 1997 budgets reflect the Visitor Center's move to the USFWS (see the disappearance of the yellow part of the bar in figure 1). Although it initially came to the NBS, it was transferred back because it did not have a science function. This facility was funded to highlight the history of USFWS science throughout the United States, including Patuxent. Instead it became a highlight of the Patuxent Research Refuge. The FY 1997 budget shows the accretion of funds to support the monitoring program (shown in red in figure 1), including the BBL, the BBS, and other monitoring functions transferred to Patuxent. There was a steady increase in funding available for research beginning in FY 1998, peaking at more than $9 million in FY 2001 (shown in white in figure 1). Monitoring funds also increased, to a little less than $3 million in FY 2001. By FY 2001, research funding at Patuxent had returned to the level seen in FY 1993, before implementation of the NBS, which was able to support its return to national and international engagement.

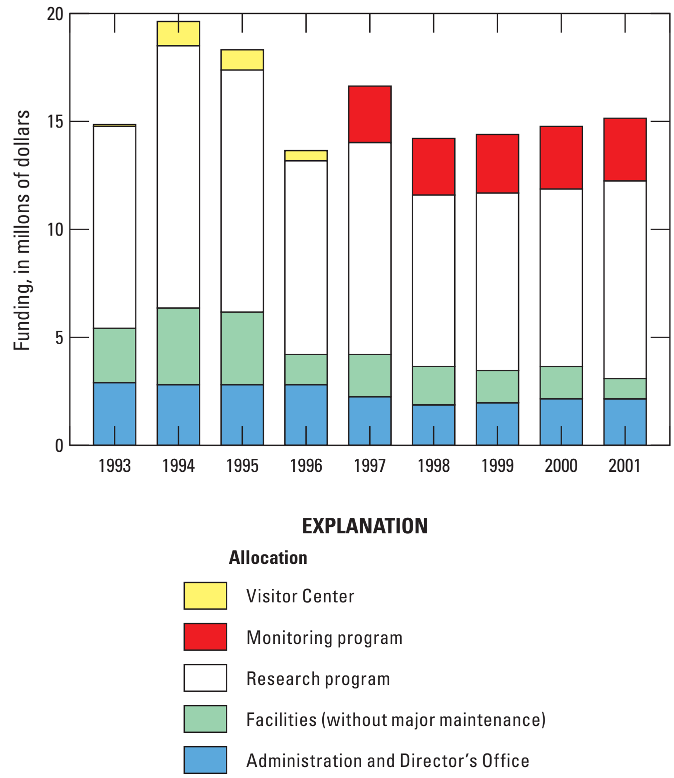


Figure 1. History of Patuxent Wildlife Research Center funding allocations, 1993–2001. (Graph modified from an unpublished presentation made by J.A. Kushlan at a meeting of Patuxent Wildlife Research Center staff, Laurel, MD, January 23, 2001.)

Facilities and the Land

Unexpectedly, facilities issues as well as science drove much of the transition at Patuxent's Laurel, MD, campus. Historically, as noted above, Patuxent and the land on which it stood were indistinguishable. The director of Patuxent was responsible for the research and for the land, which was used entirely for research, and facilities were built and converted to support it. From this trust of land and facilities came many of the internationally known fundamental management protocols for wetlands, refuge impoundments, game-bird enhancement, endangered species conservation propagation, bird banding, migratory bird conservation, contaminant studies, and the long list of other wildlife management advances. Patuxent and the lands were one. This relation became more complicated when additional lands, to be known as the South Tract and the North Tract, were accreted to the historic Central Tract from other Federal entities in the early 1990s. These lands were not intrinsically useful for research, but did add public use and even consumptive uses to the mix of management needs. Research and public use are generally not really compatible activities.

Facilities money in support of research at Patuxent disappeared in four steps. Many of the research facilities and buildings at Patuxent were old, some historically so. It was certainly the case that in adding lands and the Visitor Center, funds that used to support these research facilities on the Central Tract were now used for broader purposes, resulting in an acceleration of degradation of the research facilities. Second, when deep budget cuts hit the NBS in FY 1994–95 and, because of the past history of Patuxent management accreting nonresearch responsibilities, Patuxent lost half of its facilities funds (see above). I recall well making a speech to the staff to urge them to think of Patuxent as consisting of people, not land and buildings—good for morale, but the land and the historic buildings were in Patuxent's "blood."

The Future

This story as of this writing (2016) ended two decades ago; so much of what was then "future" has already passed. There have been three subsequent Patuxent directors and a USFWS refuge manager. Patuxent moved much of its staff to the USDA Beltsville Research Station and collapsed its office presence to one building. The biology discipline is no longer an organizational unit of USGS. Since 2002, the USGS has divided its science programs and funding streams into the "mission areas" of climate and land-use change, core science systems, ecosystems, energy and minerals, environmental health, natural hazards, and water.

The USFWS and the USGS appeared to have engaged constructively to optimize existing science capabilities (Cohn, 2005). The next generation of managers and scientists will decide how the story of DOI biological science that began in the era of transition will proceed into the middle of the 21st century.

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I acknowledge with friendship and gratitude the people of the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center (Patuxent), who are and always were exceptional people in many ways, and those who served as leaders and partners through the years of this story. Although I cannot name all of the hundreds of people who were in this mix, I would like to express my gratitude to some by name. First, thanks to Ron Pulliam and Sue Haseltine, and Dennis Fenn (USGS), who provided input to my historic perspective on Patuxent. I thank my more experienced advisors, especially Marshall Howe, Dick Jachowski, John Tautin, Dave Trauger, and Marilyn Whitehead (USGS). I acknowledge my long-standing and ever full of advice scientific colleagues at the USGS, Patuxent, especially Dick Banks, Paul Buckley, Mike Erwin, Mercedes Foster, Roy McDiarmid, Matt Perry, Barnett Rattner, Chan Robbins, and Melanie Steinkamp. I appreciate help in preparing this chapter from Dick Banks, Harry Coulombe, Matt Perry, Bruce Peterjohn, Bob Reynolds, John Tautin, and Marilyn Whitehead (USGS, Patuxent).

References Cited

Allen, D.L., 1954, Our wildlife legacy: New York, Funk and Wagnalls, 422 p.

Ballard, I.H., 1989, The Patuxent project—Part 1—External report: Laurel, MD, Patuxent Wildlife Research Center, 152 p.

Buckley, P.A., Francis, C.M., Blancher, P., De Sante, D.F., Robbins, C.S., Smith, G., and Cannell, P., 1998, The North American Bird Banding Program—Into the 21st century: Journal of Field Ornithology, v. 68, p. 511–692. [Also available at https://sora.unm.edu/node/52264.]

Carson, R.L., 1962, Silent spring: Boston, MA, Houghton Mifflin, 368 p.

Cohn, J.P., 2005, After the divorce—Improving science at Federal wildlife agencies: BioScience, v. 55, no. 1, p. 10–14. [Also available at http://dx.doi.org/10.1641/0006-3568(2005)055[0010:ATDISA]2.0.CO;2.]

Erwin, R.M., and Blohm, R.J., 2016, Migratory Bird Program at the U.S. Geological Survey Patuxent Wildlife Research Center/U.S. Fish and Wildlife Service Patuxent Research Refuge: Transformations in management and research, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 29–44. [Also available at https://doi.org/10.3133/cir1422.]

Kushlan, J.A., 2011, Review—Wilderness warrior—Theodore Roosevelt and the crusade for America: Auk, v. 128, no. 3, p. 595–597. [Also available at http://www.jstor.org/stable/10.1525/auk.2011.128.3.595.]

Kushlan, J.A., Steinkamp, M.J., Parsons, K.C., Capp, Jack, Acosta Cruz, Martin, Coulter, Malcolm, Davidson, Ian, Dickson, Loney, Edelson, Naomi, Elliott, Richard, Erwin, R.M., Hatch, Scott, Kress, Stephen, Milko, Robert, Miller, Steve, Mills, Kyra, Paul, Richard, Phillips, Roberto, Saliva, J.E., Syderman, Bill, Trapp, John, Wheeler, Jennifer, and Wohl, Kent, 2002, Waterbird conservation for the Americas—The North America Waterbird Conservation Plan (ver. 1): Washington, D.C., Waterbird Conservation for the Americas, 78 p. [Also available at http://www.waterbird-conservation.org/nawcp.html.]

Matthiessen, Peter, 1959, Wildlife in America: New York, Viking Press, 304 p.

National Academy of Sciences, 1992, Science and the National Parks: Washington D.C., National Academy Press, 136 p. [Also available at http://dx.doi.org/10.17226/2028.]

O'Connor, R.J., Dunn, Erica, Johnson, D.J., Jones, S.L., Petit, Daniel, Pollock, Ken, Smith, C.R., Trapp, J.L., and Welling, Erum, 2000, A programmatic review of the North American Breeding Bird Survey: Laurel, MD, U.S. Geological Survey Patuxent Wildlife Research Center, 36 p., accessed December 21, 2015, at http://www.pwrc.usgs.gov/BBS/bbsreview/bbsfinal.pdf.

Patuxent Wildlife Research Center Quality Council, 1993, Strategic plan—Patuxent Wildlife Research Center, National Biological Survey: Laurel, MD, Patuxent Wildlife Research Center, 139 p.

Perry, M.C., 2004, The evolution of Patuxent as a research refuge and a wildlife research center: Laurel, MD, U.S. Geological Survey, Patuxent Wildlife Research Center, 20 p., accessed September 13, 2011, at http://www.pwrc.usgs.gov/history/cronhist/patuxenthistory_perry.pdf.

Perry, M.C., 2016, Patuxent's development—The people and the projects, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 1–12. [Also available at https://doi.org/10.3133/cir1422.]

Pulliam, H.R., 1998a, The political education of a biologist, part 1: Wildlife Society Bulletin, v. 26, no. 2, p. 199–202. [Also available at http://www.jstor.org/stable/3784037.]

Pulliam, H.R., 1998b, The political education of a biologist, part 2: Wildlife Society Bulletin, v. 26, no. 3, p. 499–503. [Also available at http://www.jstor.org/stable/3783762.]

Robbins, C.S., 1977, Data bank of North American breeding bird censuses: Polish Ecological Studies, v. 3, no. 4, p. 95–98.

Robbins, C.S., 2016, Early avian studies at Patuxent, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 13–24. [Also available at https://doi.org/10.3133/cir1422.]

Scott, J.M., and Sparrowe, R.D., 1999, 1999 review of Patuxent's Whooping Crane Research Program: accessed October 15, 2012, at http://www.pwrc.usgs.gov/research/cranes/whoop2.htm.

Stone, Richard, 1993, Babbitt shakes up science at Interior: Science, v. 261, no. 5124, p. 976–978. [Also available at http://dx.doi.org/10.1126/science.261.5124.976.]

Tautin, John, 2008, A history of the Bird Banding Laboratory—1920–2002, *in* Jackson, J.A., Davis, W.E., Jr., and Tautin, John, eds., Bird banding in North America—The first 100 years: Cambridge, MA, Memoirs of the Nuttall Ornithological Club, no. 15, p. 65–91.

Tautin, John, 2016, The Bird Banding Laboratory—Support for and collaboration with research at Patuxent, *in* Perry, M.C., ed., The history of Patuxent—America's wildlife research story: U.S. Geological Survey Circular 1422, p. 45–52. [Also available at https://doi.org/10.3133/cir1422.]

U.S. NABCI Committee,, 2000, The North American Bird Conservation Initiative in the United States—A vision of American bird conservation: Washington, D.C., U.S. North American Bird Conservation Initiative Committee, 20 p. [Also available at http://digitalmedia.fws.gov/cdm/ref/collection/document/id/1443.]

Facility and Research Initiatives at Patuxent for the New Millennium

Judd A. Howell

The Challenge

When I came to Maryland in 2002, I realized facilities at the Patuxent Wildlife Research Center (Patuxent) had been allowed to languish for several decades due to flat budgets and more important research priorities (CTA Architects Engineers [2000] and Patuxent Joint Working Group [2003], unpub. reports available from the Patuxent Wildlife Research Center, Laurel, MD). During my interview for the position of director, two points became very clear to me: that I needed know about facilities and that I needed to know about leadership. Both would be the challenge during my tenure at Patuxent.

First Steps

Literally, the first step was to repair the brick steps leading to Merriam Laboratory. Bricks were falling out of the steps while yellow tape and orange cones restricted passage. The work eventually had to be redone by a mason who understood historic restoration, but the effort was symbolic. It was a simple job, certainly not the highest priority, but it was highly visible and represented safe passage for the people who worked in the building. The effort showed that something was going to be done. Step 2 required hiring a new facilities manager to stabilize the facilities situation at Patuxent while plans for its modernization could be completed.

By the time I arrived, a committee from the U.S. Geological Survey (USGS) and U.S. Fish and Wildlife Service (USFWS) had developed a facilities restoration plan with a cost of $120 million (Patuxent Joint Working Group, 2003, unpub. report available from the Patuxent Wildlife Research Center, Laurel, MD). Although the plan would completely restore both agencies' infrastructure, the high price tag was an impediment to its adoption.

The Move

Having been at Patuxent for 8 months, I began to think about my first holiday message. I had been keeping staff informed about Patuxent activities with an informal message called "Thought from this Corner" (referring to my corner office), which I sent by e-mail periodically. In the third paragraph of the holiday thought, I discussed the need to abandon Stickel Laboratory, move perhaps to Beltsville Agricultural Research Center (BARC) in Beltsville, MD, and consolidate other personnel in Gabrielson Laboratory. Then I left for vacation.

By the time 2003 had begun, Patuxent was buzzing about the move. Patuxent had regular monthly meetings for all hands, including those at field stations. Generally, field station employees phoned in to listen and ask questions. By the time of the first Patuxent center-wide meeting of 2003, I had received many negative e-mails in response to the December "thought" regarding the possible move. The day of reckoning had arrived. While everyone assembled in the large conference room, I donned a highway safety vest and a hard hat, and drew a big red bull's-eye that I taped to my chest. The sound emanating from the conference room as I approached resembled that produced by a hive of bees. I stood outside the door to let the excitement build and then I entered. The room suddenly went quiet, and then someone laughed, as did others. The room seemed to fill with smiles and grins.

I said, "Okay, we have some tough work to do, so go ahead and take your best shot." I laid out the plan to move, dressed in vest, hardhat, and target. That bit of tomfoolery set the tone and lightened the mood. As a result, Patuxent worked through the tough details of abandoning Stickel Laboratory, moving out of Merriam and Nelson Laboratories, and relocating a third of the staff to BARC. The move was to be interim until new and renovated facilities were completed at Patuxent. Although some of the early sentiment was that this would destroy the unity of Patuxent, the spirit of the people remains the core of what makes Patuxent a great research institution. After seeing the completed upgrade of the Beltsville Laboratory, one scientist even asked to be relocated there. I said no, that some of us needed to share the discomfort of crowded conditions until the entire restoration of Patuxent was completed.

New Blood, New Thrusts

In the face of more than 12 years of flat budgets and an older, retiring workforce, it was imperative that the next generation of great scientists at Patuxent be recruited. During

Diann Prosser, U.S. Geological Survey, in Mongolia with swan goose instrumented with solar-powered transmitter, 2006. Photo by John Takekawa, U.S. Geological Survey.

Alicia Berlin, U.S. Geological Survey, weighing common eider in seaduck colony for selenium study at Patuxent Wildlife Research Center, Laurel, MD, 2004. Photo by Matthew C. Perry, U.S. Geological Survey.

my tenure, I oversaw the hiring of a research zoologist, Terry Chesser, at the National Museum of Natural History; a research statistician, Andy Royle, and a research ecologist, Sarah Converse, for the quantitative methods group at Patuxent; a research ecologist, Natalie Karouna-Renier, for the contaminants group; and a statistician, Clint Moore, for quantitative methods at the Athens, GA, field station. Wildlife biologist Mark Wimer was hired full time for the Breeding Bird Survey, and wildlife biologist Monica Tomosy became the new chief of the Bird Banding Laboratory (BBL), which was transformed and reengineered under her leadership, with the assistance of the computer scientist, Kevin Laurent, and the Herculean efforts of the BBL staff.

Two Student Career Experience Program Ph.D. students who worked at Patuxent during my tenure stand out. Alicia Berlin, under the direction of research biologist Matthew Perry, completed her dissertation about seaducks using Patuxent's newly constructed seaduck dive tanks. Diann Prosser, under the direction of research biologist Michael Erwin, opened the research door to China, working with the Chinese Academy of Sciences and John Takekawa at the Western Ecological Research Center, Sacremento, CA, on a project to study the transmission of highly pathogenic avian influenza, H5N1, in migratory birds. These young and brilliant minds along with their exceptional, more experienced colleagues will most likely keep Patuxent in the forefront of wildlife research for decades to come.

The Presidential Visit

On a Saturday morning, October 20, 2007, President Bush, First Lady Laura Bush, Secretary of the Interior Dirk Kempthorne, and the wife of the Secretary of the Treasury, Wendy Paulson, came to Patuxent to make a media announcement about conservation efforts for migratory birds. As part of the event, I had the opportunity to give them a tour of

President George W. Bush and First Lady Laura Bush near the crane pens at the Patuxent Wildlife Research Center, Laurel, MD, 2007. Photo by Eric Draper, White House photographer.

First Lady Laura Bush, Secretary of the Interior Dirk Kempthorne, President Bush, Bradley A. Knudsen, and Judd A. Howell at Cah Lake, Patuxent Wildlife Research Center, Laurel, MD, 2007. Photo by Eric Draper, White House photographer.

Patuxent's Endangered Species Program facilities, especially the whooping cranes. What flashed through my mind was, "How do I tell the Secretary in 60 seconds how and why we need $82 million for the rehabilitation of Patuxent?"

I looked at my watch and said that there probably was not enough time, because the group had to move on. Instead, I asked the Secretary whether I could come to his office to have that discussion. The Secretary said that would be fine. We then proceeded with our tour.

The next event was the media event. Patuxent Research Refuge Manager Bradley A. Knudsen escorted the entourage along the lake to see wildlife, and then they headed back to the podium for the announcement, which included direction to the Secretary to add funds to the National Wildlife Refuge system (http://georgewbush-whitehouse.archives.gov/news/releases/2007/10/20071020-2.html, accessed December 30, 2015).

Winter Weather and Cranes

One defining moment for Patuxent and the Refuge was the heavy, wet snow in February 2006. That snow crushed 105 of the 110 whooping crane breeding pens. The last time that had happened was in the mid-1980s, and the breeding season had been lost. My management team and I mobilized the resource, with exceptional help from the Patuxent and Refuge staffs. In a mere 3 weeks, this highly focused, hands-on effort restored the pens to operation. The Friends of Patuxent, a volunteer support group for Patuxent, supplied the funds for the food. Director's Office staff members Marilyn Whitehead and Regina Lanning acted as chiefs for the "Crane Cafe" that fed the volunteers in the field for the long hours of labor. That year Patuxent successfully reared 17 whooping cranes to be released into the wild. The event brought the entire Patuxent community together in a spirit of common cause that I will never forget.

The Final Plan

With the considerable work from all levels of the USGS and the USFWS, the final $82 million restoration plan for Patuxent had been elevated to the number 1 priority for funding by the Department of the Interior. Senate Appropriations staffers had outlined the best approach for a funding schedule. Water and sewer lines were connected to the local water and treatment district, and design concepts began to be formulated. It was a possible start for a new Patuxent. In June 2008, I retired and returned to California.

Judd A. Howell, U.S. Geological Survey, and his wife, Nancy Howell, with President George W. Bush in the White House Oval Office, 2007. Photo by Eric Draper, White House photographer.

Appendix 1. Contributors and Contact Information, September 2016.

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