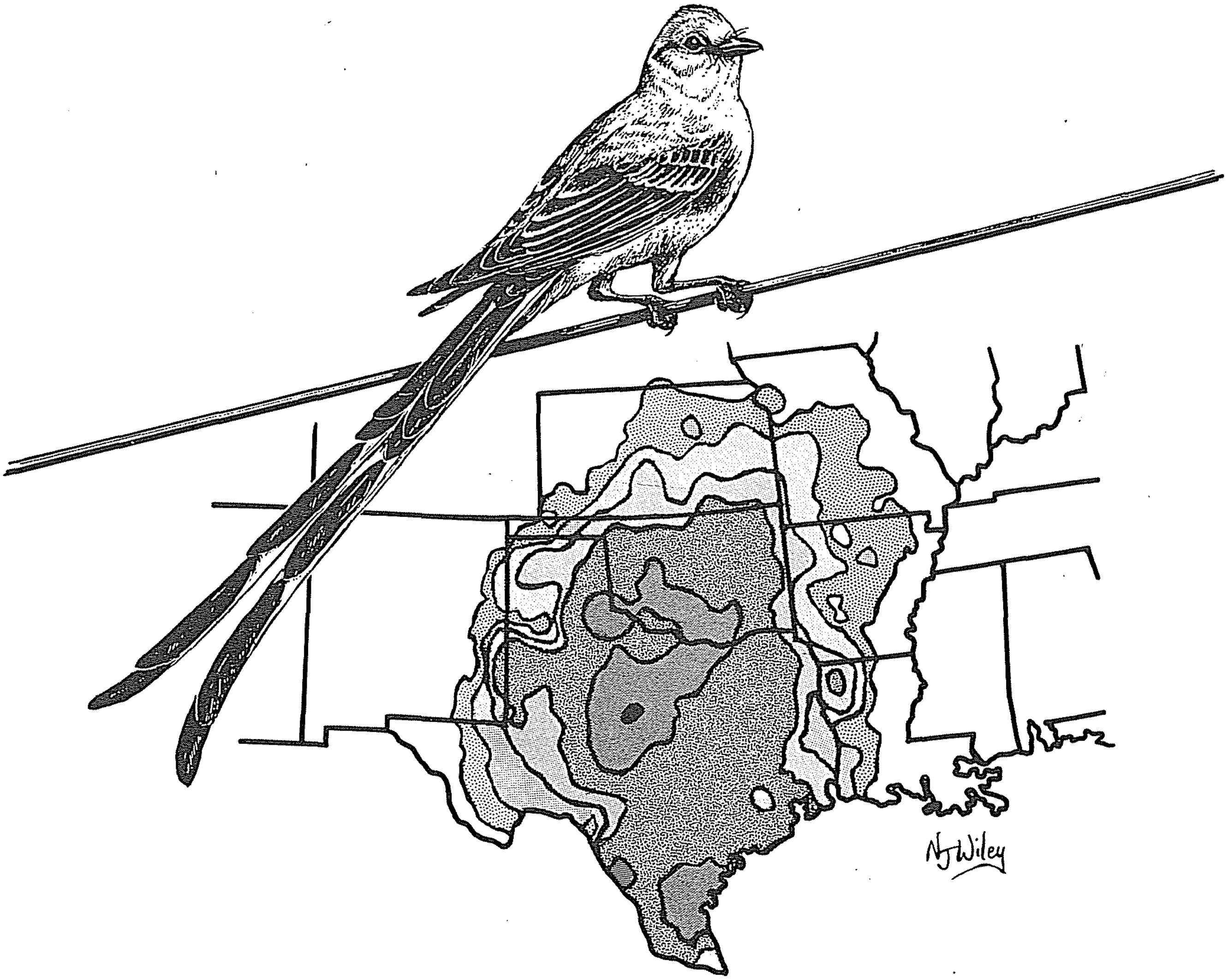
Biological Report 90(1)
January 1990

Survey Designs and Statistical Methods for the Estimation of Avian Population Trends



Fish and Wildlife Service
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Biological Report

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ISSN 0895-1926

This publication may be cited as follows:

Sauer, J. R., and S. Droege, editors. 1990. Survey designs and statistical methods for the estimation of avian population trends. U.S. Fish Wildl. Serv., *Biol Rep*. 90(1). 166 pp.

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January 1990

Survey Designs and Statistical Methods for the Estimation of Avian Population Trends

edited by

John R. Sauer and Sam Droege

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Preface

On 12–13 April 1988 a workshop on the analysis of avian population trends was held at the Patuxent Wildlife Research Center in Laurel, Maryland. The workshop was cosponsored by the Branch of Migratory Bird Research of the Patuxent Wildlife Research Center and the Office of Migratory Bird Management. During this workshop, we hoped to bring together some of the biologists and statisticians that coordinate and analyze data from major bird surveys to discuss recent advances in analytical methods of estimating population trends. The workshop had three sessions: one to describe some of the major surveys used to estimate population trends, one to discuss analytical methods, and one to consider population trends of a selected species: scissor-tailed flycatchers (*Tyrannus forficatus*), for which a data set from the North American Breeding Bird Survey had been distributed to participants before the meeting.

These proceedings present the results of the workshop. The papers are organized into three parts, following the design of the workshop. Part I is composed of papers that describe the design of major avian surveys, along with reviews of the constraints that the designs place on the analysis of population trends. Part II presents some of the major analytical methods that are used to estimate population trends. There is a good deal of diversity among the papers in this part, with some papers discussing overall approaches to surveys and their analysis, others attempting to analyze the relations among the methods, and some presenting only a specific method of analysis. Several papers broach general questions of sample size allocation for roadside surveys and associated technical questions. Part III contains three analyses of the scissor-tailed flycatcher data set: two variants of the route-regression method and a nonparametric analysis.

Acknowledgments

We thank R. I. Smith of the Office of Migratory Bird Management, and R. J. Hall and R. L. Jachowski of the Branch of Migratory Bird Research, Patuxent Wildlife Research Center, for providing us with financial support for both the workshop and the preparation of the proceedings. The Patuxent Wildlife Research Center provided logistical support for the workshop. N. Bushby and N. Hestbeck of the Branch of Technical Services, Patuxent Wildlife Research Center, coordinated the peer review of manuscripts. M. A. McKeogh assisted with many aspects of the workshop and the preparation of the proceedings. We also thank D. S. Chu, D. K. Dawson, R. M. Erwin, P. H. Geissler, and J. D. Nichols for assistance with the workshop.

Most of the participants in the workshop were called on to review at least one manuscript. We thank C. Bunck, G. S. Butcher, D. Bystrak, J. T. Cary, B. T. Collins, D. K. Dawson, R. T. Engstrom, R. M. Erwin, M. R. Fuller, P. H. Geissler, J. M. Hagan, G. A. Hall, J. Hatfield, M. A. Howe, F. James, D. W. Johnston, M. K. Klimkiewicz, W. Link, C. E. McCulloch, J. D. Nichols, B. R. Noon, R. J. O'Connor, G. Pendleton, C. S. Robbins, C. R. Smith, J. R. Spendelow, S. R. Taub, K. Titus, and J. Verner for their efforts in manuscript review. L. Hungerbuhler and M. A. McKeogh typed several of the manuscripts.

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Part I: Surveys Used to Estimate Avian Trends

For most of the surveys discussed in the workshop, trend analyses have traditionally involved (1) identifying a dependent variable that indexes population size at one of a group of survey sites (or routes) and (2) estimating population changes (trends) over time in some way that takes into account the intrinsic features of each site. In this part of the workshop, we discussed some of the sources of information used to estimate bird population trends, and we attempted to identify some of the constraints that the underlying sources of information placed on the selection of a relevant dependent variable and the analytical method of estimating trends.

In some surveys, the dependent variables used to index population size at a site in a year are "natural," such as the total number of individuals heard or seen over the 50 stops of a Breeding Bird Survey route, or the population estimates from a Common Bird Census, Breeding Bird Census, or a colonial bird count. In other surveys, count data must be adjusted to control for variation in observer effort, such as occurs in the Christmas Bird Count, migration banding, hawk counts, or the International Shorebird Survey. Finally, in certain surveys, presence or absence data must be converted to estimates of proportion-of-area-occupied data for analysis, as in breeding bird atlases or checklist projects. All surveys, however, share a common problem: the yearly index values are not statistically based estimates of population size, but instead are assumed to be related to population size by a proportionality constant (Bart and Schoultz 1984). Standardization of survey procedures and a posteriori adjustments of indices by effort, discussed in this section, represent attempts to minimize variation in this proportionality constant. We recommend that readers see Lancia et al. (in press) for a detailed discussion of the consequences of assuming a constant relation between population indices and population parameters.

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The North American Breeding Bird Survey

by

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Origin and Extent of Survey

The North American Breeding Bird Survey (BBS) is coordinated and maintained by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service. Its purpose is to provide long-term information about the abundance and distribution of breeding birds in the United States and Canada. Data exist for more than 500 species. More than 400 of these species have been recorded on more than 50 survey routes (Erskine 1978; Robbins et al. 1986; Droege and Sauer 1989).

The BBS was designed and initiated by C. S. Robbins. In 1966 routes were first run in the eastern States and Provinces. In 1967 the survey was expanded to include the central States and Provinces, and by 1968 the entire continent was included.

Design of the BBS

Individual BBS routes are 24.5 miles long and comprise 50 point counts spaced one-half mile apart. Each point count, or stop, extends for 3 min. During this period the observer counts all birds heard singing or calling and any bird sighted within a quarter-mile radius. The density of BBS routes in a State or Province varies with the available number of observers. Density is highest in the East and lowest in the Intermountain West and northern boreal zones (Figure). Once an appropriate density of routes has been estimated for a State or Province, routes are stratified by degree blocks of latitude and longitude (e.g., 1 per degree block in Nevada and 16 per degree block in Maryland). Within a degree block, starting points are chosen at random, as are directions of travel. The actual roads the route follows are constrained by their availability and traffic. With a few exceptions, routes do not cross degree blocks or physiographic strata boundaries.

Each route is run once a year by a skilled volunteer. Most routes are run during June. However, routes in portions of Arizona, California, Florida, Nevada, New Mexico, and Texas are often run in May, and some northern routes are run during the first week of July.

Data are submitted by the observer to the Office of Migratory Bird Management, U.S. Fish and Wildlife Service, Laurel, Maryland, both on original field sheets and on summary sheets. These data are checked for transcriptional, mathematical, and biological errors on arrival. Each summary sheet is cataloged, entered into a data base, and then verified. Data are sent through several computer routines that check for clerical and mathematical errors. Every route is checked against regional lists of expected species. Unusual species are flagged on printouts of a route's data and sent to the observer who double checks the work and, if necessary, sends further documentation. Data collected under poor weather conditions or by observers with insufficient ability to accurately census birds are coded but not used in subsequent analyses.

Constraints on the Analysis of the BBS

Differences in regional density of routes and consistency in coverage (Figure) affect our ability to track regional populations. Most BBS routes have had gaps in coverage during the past 22 years. Gaps occur when observers are unavailable or if a completed survey is deemed unsuitable. Statistical analysis of BBS data requires special care because of the relatively large amount of missing data. Simple yearly means can produce deceptive results, especially if data are missing from routes containing very high or low densities of the species being analyzed (Geissler and Sauer 1990). Every region has, to some extent, missing data problems. Additionally, almost every region has had new routes added and old ones discontinued, further adding to the problems of unbalanced data. The number of BBS routes run also varies with year. During the first years of the program, coverage was of relatively low intensity. Small sample sizes reduced our ability to accurately track population changes.

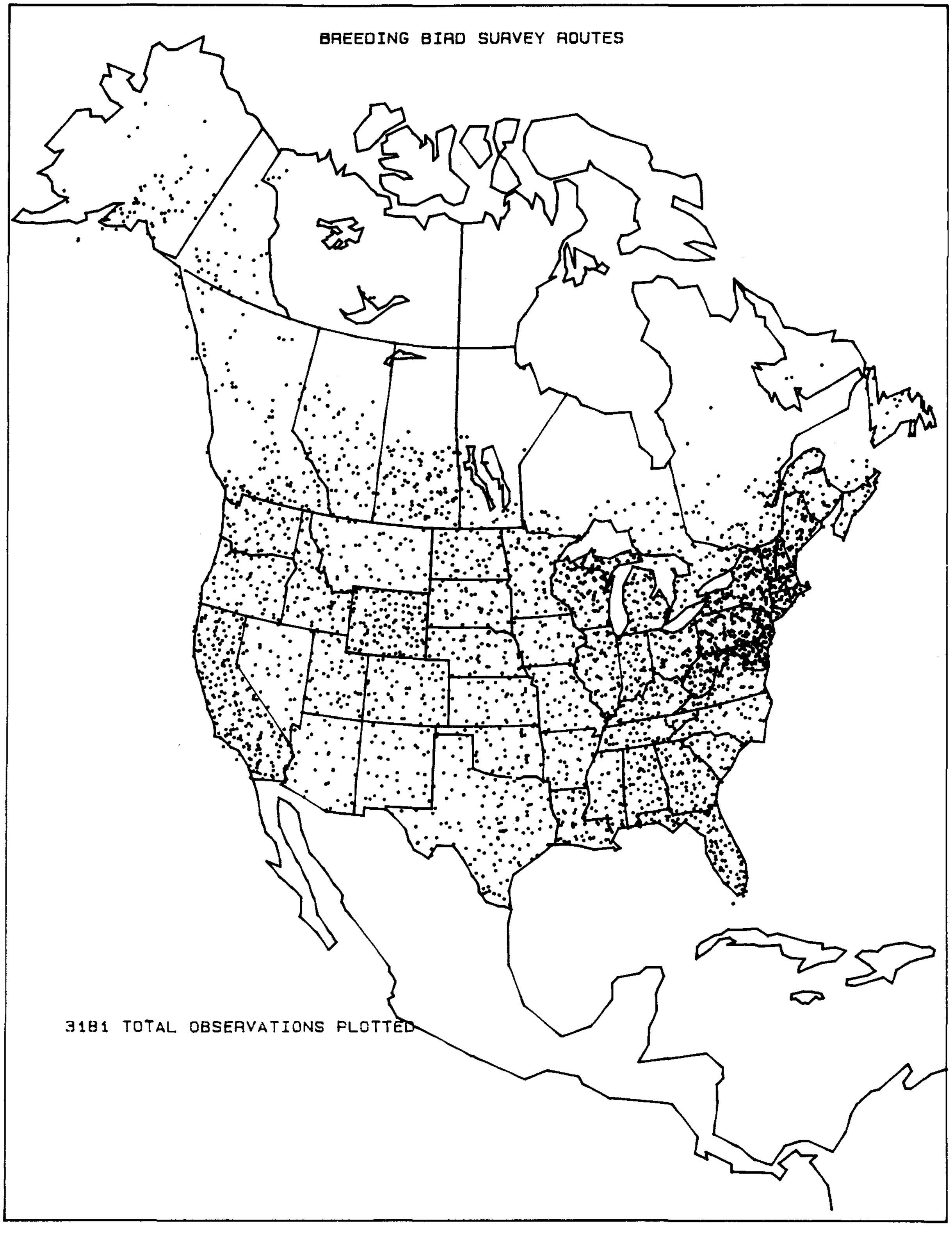

Figure. Distribution of Breeding Bird Survey routes.

Most of the United States and Canada have an extensive network of secondary roads. The random placement of BBS routes in these regions is relatively straightforward. However, in some portions of the mountainous west (e.g., the Great Basin) and the far north (e.g., Northwest Territories), roads are fewer and tend to occur in valleys and near watercourses. In regions of low relief, riparian zones are likely to be undersampled because most roads travel across rather than within floodplains. The location and design of regional road networks will influence calculations of avian relative abundance. Unfortunately, we will not know how well BBS routes represent regional habitats until LANDSAT data and associated technologies become more available.

Roadsides can be considered unique habitats in some regions. Most roads act as boundaries, creating edge habitats populated by speeding metallic predators. They often parallel superb song and hunting perches, such as telephone lines and fences. How dissimilar roadside stops are from random geographic points and how dissimilar rates of roadside bird population change are from the entire landscape's rate of change are currently unknown. However, at least in regions of low elevational relief, all common diurnal species appear to be well represented on BBS routes, although perhaps not relative to their true abundance.

Observers vary in their ability to hear, identify, and estimate the abundance of birds (Faanes and Bystrak 1984). Even among experienced observers, large differences exist in how numbers are estimated (Bart and Schoultz 1984). Wherever possible, observer covariables should be included in statistical analyses of BBS data (Geissler and Sauer 1990).

Flocking and colonial birds present special problems because of their greater variation among yearly counts (Sauer and Droege 1989). Variation often results from localized concentrations of feeding birds (e.g., gulls, herons, vultures) or stops near colonies (e.g., swallows). This variation can be reduced if the number of stops at which the birds were seen are used to calculate trends rather than total number of individuals (Bart and Klosiewski 1989). However, the number of stops at which a species is present is a measure of the area the species occupies rather than a direct measure of its abundance.

The number of individuals recorded on a BBS route is both a function of a species' detectability and its true abundance. Detectability varies among species, observers, and habitats, and with time of year, weather, density, and the male's breeding status (Emlen 1971; Berthold 1976; Marten and Marler 1977; Ralph and Scott 1981). Due to these differences in detectability, relative abundance is not directly comparable between species. Detectability can also change with local population density. Hence, the relation between BBS counts and true density could be curvilinear or even a step-function. Because the life histories of the surveyed populations are almost always poorly known it is difficult to make generalizations about the BBS's sensitivity to true population change. Statistical analyses of these data and their subsequent interpretation should dwell on the patterns of population change rather than on the magnitudes of calculated trends and variances. Variations associated with weather conditions and time-of-year are minimized by only accepting data from routes run during acceptable conditions.

Several recent studies have sought to corroborate population trends on BBS routes with data from independent surveys. Carolina wren (*Thryothorus ludovicianus*) numbers from Indiana May Counts closely correspond to BBS annual indices calculated for the same region (E. Hopkins, personal communication). Raptor counts from migration stations and Christmas Bird Counts (CBC) show good corroboration for those species commonly detected on BBS routes (Schueck et al. 1989; Titus et al. 1989). State long-term trends for mourning doves (*Zenaida macroura*) from the Mourning Dove Survey are correlated with BBS trends calculated from the same States (J. R. Sauer, personal communication). Preliminary work with several species recorded commonly on both BBS routes and CBC's also yield similar population trends (Butcher et al. 1990). Population trends derived from the Quebec checklist program are in almost complete concordance with the sign of trends from BBS routes in Quebec (A. Cyr, personal communication).

We will continue to investigate and catalog the relative strengths and weaknesses of the BBS data set and encourage others to do likewise.

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Audubon Christmas Bird Counts

by

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Origin and Current Design of the Christmas Bird Count

The Christmas Bird Count (CBC) is the oldest and largest wildlife survey in the world. It is sponsored by the National Audubon Society, and the results are published in *American Birds*. It began in 1900 when 26 individuals responded to an editorial in *Bird-Lore* magazine (Chapman 1900) by spending an hour or two counting birds in their neighborhood on Christmas afternoon. Since then, the increase in both the number of counts (Fig. 1) and the number of participants (Fig. 2) has been dramatic. In 1986–87, 41,249 individuals participated at 1,544 locations, including 1,508 locations in the United States (excluding Hawaii) and Canada (Table 1).

All CBC's occur within a 15-mile-diameter circle. Each local CBC coordinator chooses a single calendar day within 2 weeks of Christmas Day for each year's count. Each local CBC is conducted by between 1 and 230 field observers, who spend between 1 and 650 party-hours and 0 and 4,100 party-miles looking for birds (Butcher and McCulloch 1990). Each local CBC also includes between 0 and 343 individuals recording birds at home. Most party-miles are covered by car; party-hours can include hours on foot, bicycle, skis, snowshoes, snowmobile, car, boat, and airplane. Many counts include nocturnal party-hours and party-miles.

Every CBC has one or more count coordinators, who are responsible for recruiting participants, assigning participants to areas, providing overall guidance to participants, compiling the results, securing written or photographic descriptions of rare species, and sending the results to the National Audubon Society. Most coordinators divide the count circle into areas and assign one group to each area. Participants are instructed not to count birds out of their assigned area. Rarities may be staked out ahead of time, and known birding "hot-spots" may be revisited several times during the day. When areas are revisited (and when counting at feeders), participants record only the

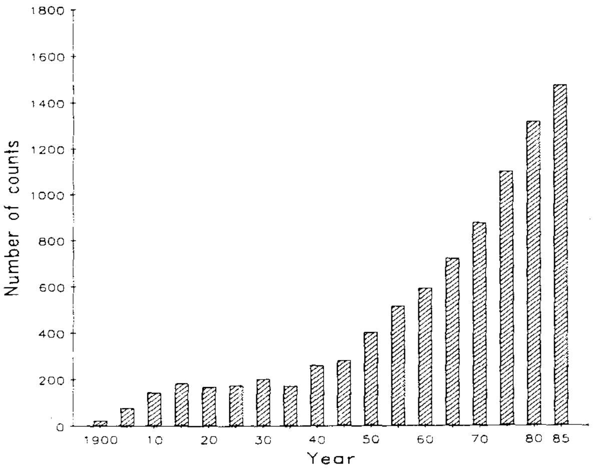

Fig. 1. The number of Christmas Bird Counts done each year has grown dramatically from 1900 to 1985.

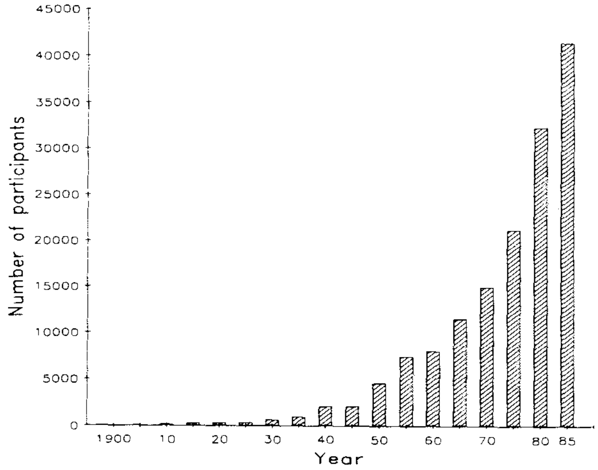

Fig. 2. The number of participants in Christmas Bird Counts has grown dramatically from 1900 to 1985.

Table 1. *Physiographic regions of the United States and Canada, excluding Hawaii.*

1	Subtropical
2	Floridian
3	Coastal Flatwoods
4	Upper Coastal Plain
5	Mississippi Alluvial Plain
6	Coastal Prairies
7	South Texas Brushlands
8	East Texas Prairies
9	Glaciated Coastal Plain
10	Northern Piedmont
11	Southern Piedmont
12	Southern New England
13	Ridge and Valley
14	Highland Rim
15	Lexington Plain
16	Great Lakes Plain
17	Driftless Area
18	St. Lawrence River Plain
19	Ozark–Ouachita Plateau
20	Great Lakes Transition
21	Cumberland Plateau
22	Ohio Hills
23	Blue Ridge Mountains
24	Allegheny Plateau
25	Open Boreal Forest
26	Adirondack Mountains
27	Northern New England
28	Northern Spruce–Hardwoods
29	Closed Boreal Forest
30	Aspen Parklands
31	Till Plains
32	Dissected Till Plains
33	Osage Plain–Cross Timbers
34	High Plains Border
35	Rolling Red Prairies
36	High Plains
37	Drift Prairie
38	Glaciated Missouri Plateau
39	Great Plains Roughlands
40	Black Prairie
53	Edwards Plateau
54	Rolling Red Plains
55	Staked Plains
56	Chihuahuan Desert
61	Black Hills
62	Southern Rocky Mountains
63	Fraser Plateau
64	Central Rocky Mountains
65	Dissected Rocky Mountains
66	Sierra Nevada
67	Cascade Mountains
68	Northern Rocky Mountains
80	Great Basin Deserts
81	Mexican Highlands
82	Sonoran Desert
83	Mojave Desert
84	Pinyon–Juniper Woodlands
85	Pitt–Klamath Plateau
86	Wyoming Basin
87	Intermountain Grasslands
88	Basin and Range
89	Columbia Plateau
90	Southern California Grasslands
91	Central Valley
92	California Foothills
93	Southern Pacific Rainforests
94	Northern Pacific Rainforests
95	Los Angeles Ranges
96	Southern Alaska Coast
98	Willamette Lowlands
99	Tundra

maximum number of individuals of a particular species seen at one time. Most count coordinators try to cover as much of the count circle as the number of participants and accessibility will allow. Most count coordinators serve for many years, and many participants cover the same areas year after year.

Evaluation of the CBC Design

There are a number of standards that should be met, to some degree, if a survey or census technique is to be used for studies of changes in relative abundance through time or space. The CBC does have standardized techniques, some of which were presented earlier. However, certain important factors, such as the route covered and the amount of effort, are not standardized. In some cases, count locations don't remain constant. In this section, I list the ideal for a standardized count, then compare the CBC design with the ideal.

Year-to-year Changes in Coverage

The most basic point is that a survey should be done the same way in different areas and in different years. However, on the CBC, the amount of effort spent looking for birds (as measured by observers, hours, or miles) varies dramatically between count locations within years and within count locations between years (Butcher and McCulloch 1990). Also, individuals cover their area of the CBC circle in a variety of ways. For example, some observers may use boats in some years and not in other years. This methodological difference can have a dramatic effect on the number of waterfowl counted. Similarly, some participants stay near their cars in cold or wet years, but walk longer distances in warm, dry years. This difference can dramatically affect the number of landbirds counted. Wilds (1980) pointed out an interesting bias through time: birders avoid urban areas; thus, when a circle becomes increasingly urban, birders move their efforts to the less-developed parts of the circle. Despite all these variations that can occur, in fact most observers cover the same areas year after year in essentially the same way. In summary, coverage varies from year to year, but remains very similar.

Count circles may change location yet keep the same name. The change may be as little as 1% or as much as 100%. Count circles may stay in the same place, but report different latitude-longitude coordinates or a different name. Deciding whether a similar location in different years is the same location requires detective work and individual judgment.

Expertise and Diligence of CBC Participants

In a standardized survey, reported numbers should be representative of what is in the study area on the day of the survey. For this to be true for CBC's, birders should know how to identify birds and should be competent and diligent at recording numbers of individuals. In a standardized survey, a coordinator might screen observers for ability and train them until they meet minimal criteria. In the CBC, beginners participate often without training. However, beginners are almost always assigned to parties with an experienced birder. Expert birders are patchily distributed throughout the country; some counts will have many expert birders, others will have few or none. Groups that lack expert birders will make errors in identification; however, gross errors are weeded out by the extensive editing system supervised by the National Audubon Society. Editors in this system include count coordinators, State editors, and national editors. An interesting bias relating to identification errors exists through time: birders are getting better at identifying birds because field guides are getting better, optical equipment is getting better, and new identification tips are proliferating. Thus, there may be a built-in bias towards increase in numbers for species that are (or were) even moderately difficult to identify. We know that participants are more interested in finding rare species than counting common species; however, participants do count common species, even if it is not always their primary interest.

Representativeness of CBC Locations

If a goal of a survey is to extrapolate results to a larger region than the area being surveyed, then the areas included in the survey should be representative of the areas not included. For this to be true, surveys should be widely distributed in the area of interest and should include habitats that are representative of nearby areas that are not surveyed. Ideally, census-survey locations should be assigned on a stratified basis, perhaps by degree block of latitude-longitude, by physiographic region, or by vegetation type; within the stratified units, survey locations are often randomly chosen.

CBC locations are chosen by local count compilers. As Fig. 3 shows, CBC's are not randomly distributed. They are concentrated near cities; however, they avoid inner cities. Thus, suburban areas are over-represented and remote areas under-represented, although some high-quality areas far from cities are sought out for CBC's.

Bystrak (1981) divided North America into a number of physiographic regions. Plants and birds should be more similar to each other within those regions than between them. I used an updated version of Bystrak's regions to determine the percentage of coverage of each region by CBC's, assuming that the entire CBC circle was covered (Table 2). In the winters of 1982–83, only five northern regions were covered less than 1% by CBC's (Fig. 4).

Timing of Counts

Birds are most sedentary during the breeding season and least sedentary during spring and fall migration. Thus, winter is the second best season for consistent bird counts. CBC's can occur during early winter from 15 December to 5 January. Bad weather within this

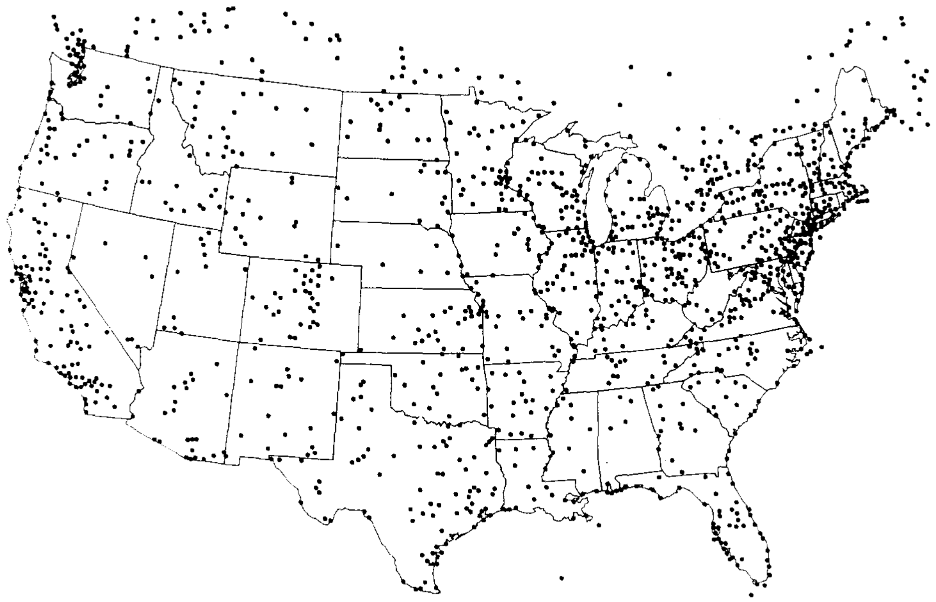

Fig. 3. A map of the locations of all Christmas Bird Counts in the 48 contiguous United States and southern Canada submitted to the National Audubon Society for the winter of 1982–83.

period may cause movements of birds during the survey; year-to-year differences in the severity of early-winter weather may cause dramatic fluctuations in reported numbers for some species. Bad weather on a local count day may depress both observer effort and bird activity (see references in Ferner 1984); however, counts are rarely rescheduled due to bad weather. Luckily, many CBC's occur at the same time each year.

Recommendations for Using CBC Data

Researchers who use CBC data should:

- be aware of potential identification problems for their species of interest (e.g., accipiters [Daniels 1975], Thayer's gull, *Larus thayeri* [Mark 1981]);
- be aware of potential counting biases (Arbib 1981; Bock and Root 1981);
- be aware of biases in habitat coverage (Wilds 1980; Bock and Root 1981);
- be aware of the possible effects of cold or wet weather either before or during a CBC (see references in Ferner 1984);
- decide whether to split or lump count locations that have moved slightly between years;
- determine how effort affects the counts of their species of interest (Butcher and McCulloch 1990);
- consider the use of reference species, especially when individuals of a species might be encountered by more than one type of effort (Raynor 1975; Bock and Root 1981; Haney 1983); and
- use a number of CBC locations and years for any study (Bock and Root 1981).

Why Use CBC Data?

The CBC is a birdwatching event, not a scientific event, and always has been. Why then should scientists pay any attention to the information collected during CBC's? The major reason is that the CBC is one of only two surveys in the world that collects information on relative abundance over a large proportion of an entire continent for a large proportion of that continent's species. The other survey is, of course, the Breeding Bird Survey (BBS) of the U.S. Fish and Wildlife Service and the Canadian Wildlife Service. CBC data are useful because they complement the BBS, which is conducted in early summer.

A number of species are encountered frequently on CBC's that are rarely encountered on the BBS. These include raptors (Table 3) and coastal and wetlands species (Table 4). In 1977, 322 species were seen on 20 or more BBS routes (Robbins et al. 1986); in 1982–83, 362 species were seen at 20 or more CBC locations (Table 5). A total of 451 species appear on one or both lists. Based on an arbitrary standard, BBS data are better for 241 species, and CBC data are better for 210 species (Table 5).

Ninety-nine species were seen on 100 or more BBS routes and at 100 or more CBC locations; these species can be used to compare population dynamics for the same species from the two different surveys to see if similar trends are produced from both data bases. Butcher and Fuller (1986) studied population trends of seven species using the two data bases. Six of the seven species showed qualitatively similar trends. Only the eastern bluebird (*Sialia sialis*) showed different trends on the two data bases. The eastern bluebird is a weather-sensitive species with widely varying population levels from year to year; thus, it is inappropriate to try to summarize its population dynamics with a single trend line.

Other sources of bird population information also correlate well with CBC data. Butcher (1986) found that the American black duck (*Anas rubripes*) population trend derived from CBC data was similar to the trend derived from the Mid-Winter Waterfowl Inventory of the U.S. Fish and Wildlife Service. Robbins (1970, 1978) and Robbins and Bystrak (1974) experimented with a carefully controlled winter survey for 5 years in Maryland. They found that both population trends and yearly population indices were similar, using data from their experimental survey and nearby CBC's. Dunn (1986)

Table 2. *Proportion of physiographic regions covered by CBC's.*[a]

Coverage (%)	1963–64	1982–83
>10	10	23
1 - 10	41	42
0 - 1	20	6[b]

[a] Locations of physiographic regions are shown in Fig. 4; the names of all physiographic regions are listed in Table 1.

[b] The following are the six regions that are less than 1% covered by CBC's:
25 – Open Boreal Forest
29 – Closed Boreal Forest
63 – Fraser Plateau
67 – Cascade Mountains
68 – Canadian Rocky Mountains
99 – Tundra.

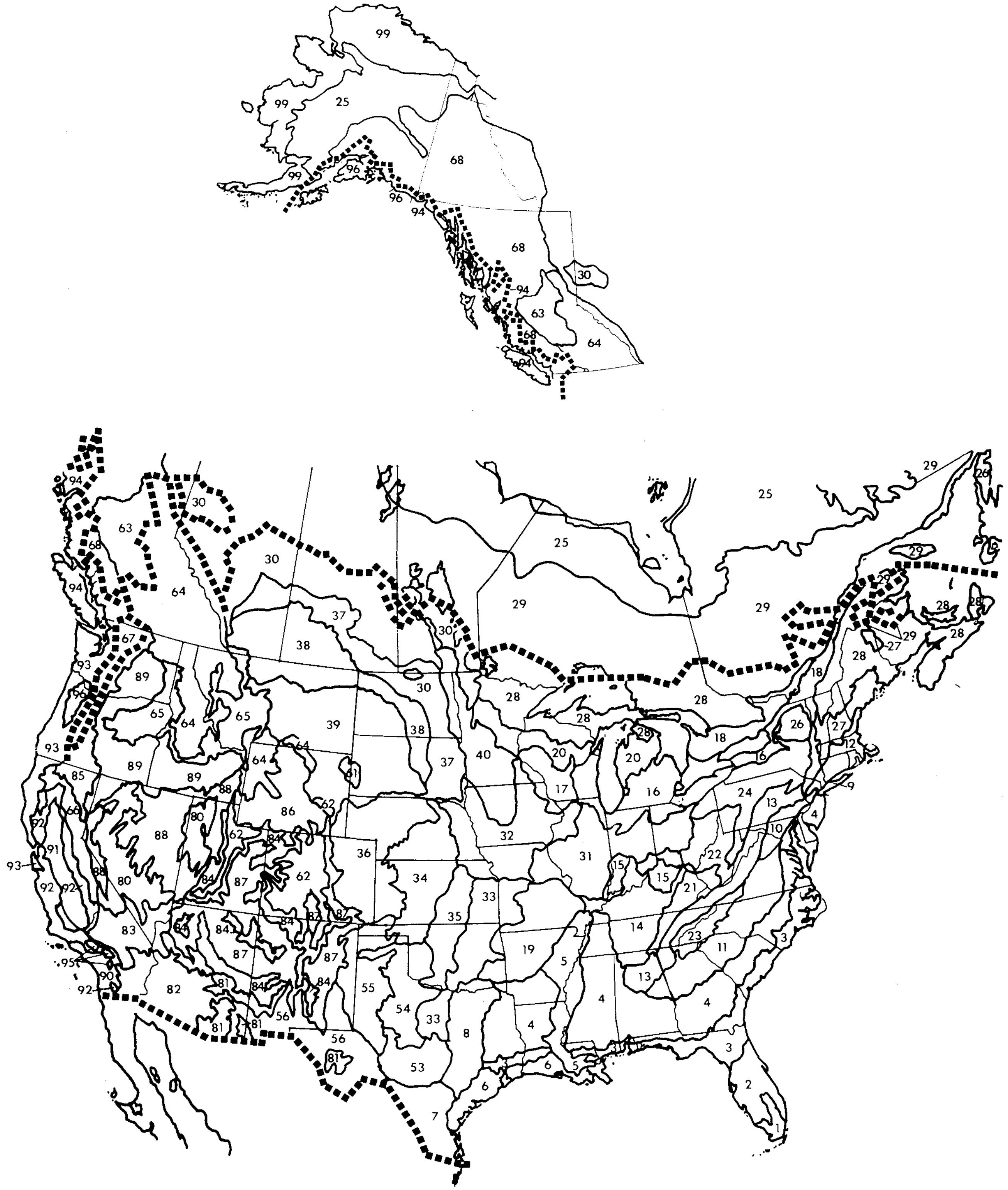

Fig. 4. This map shows the physiographic regions as determined for the Breeding Bird Survey of the U.S. Fish and Wildlife Service. These regions were assigned by D. Bystrak, based primarily on Aldrich (1963) and modified by Bureau of Agricultural Economics (1933), Fenneman (1931, 1938), Kuchler (1964), Erskine (1978), and other sources. The names of the physiographic regions are listed in Table 1. The areas included within the *broken heavy lines* are covered 1% or more by CBC circles (Table 2).

Table 3. *Frequency of encounter of raptors on the Christmas Bird Count and the Breeding Bird Survey.*

	Christmas Bird Count (1982–83)		Breeding Bird Survey (1977)	
Species	Total circles	Total birds	Total routes	Total birds
Black vulture	229	11,330	102	551
Turkey vulture	384	38,189	490	3,271
Osprey	109	1,479	61	104
American swallow-tailed kite	0	0	4	11
Black-shouldered kite	92	1,818	25	60
Snail kite	7	4	1	7
Mississippi kite	0	0	38	152
Bald eagle				
adult	428	4,308	12	20
immature	289	4,965	—	—
age unknown	54	768	—	—
Northern harrier	806	11,124	169	320
Sharp-shinned hawk	790	2,875	29	31
Cooper's hawk	663	1,908	53	62
Northern goshawk	292	445	5	5
Harris' hawk	28	269	12	35
Red-shouldered hawk	440	3,530	163	309
Broad-winged hawk	25	83	142	181
Swainson's hawk	8	15	124	321
White-tailed hawk	13	43	2	2
Zone-tailed hawk	1	1	2	2
Red-tailed hawk	1,206	33,786	588	1,287
Ferruginous hawk	126	427	21	37
Rough-legged hawk	610	3,491	1	1
Golden eagle				
adult	186	516	41	54
immature	109	259	—	—
age unknown	48	108	—	—
Crested caracara	20	202	8	24
American kestrel	1,109	29,633	665	1,622
Merlin	255	475	10	11
Peregrine falcon	104	166	3	3
Gyrfalcon	21	29	0	0
Prairie falcon	211	516	19	19

compared year-to-year population changes of Ontario feeder counts and CBC's and found comparable results for 12 of 25 species. Species that attended feeders infrequently and species that had relatively small population changes from year to year showed no comparable results.

Many other studies of population dynamics that used CBC data verified long-term trends or dramatic population eruptions that were known from other sources. A number of species, especially insectivorous passerines in the southeastern United States, were shown using CBC data to be sensitive to severe winter weather (James 1962, 1963); the weather sensitivity of these species was confirmed by BBS data (Robbins et al. 1986).

In summary, for all its difficulties, the CBC has an impressive record for producing useful analyses of the population dynamics of North American birds. Taken as a group, these studies prove that there is a mother lode of useful information in the CBC data base.

Creation of a Computerized CBC Data Base

The Cornell Laboratory of Ornithology completed computerization of a 30-year data base of CBC information in 1990, which will greatly aid the analysis of population dynamics of species that are frequently encountered on CBC's (the 362 species of Table 5). Trends from the BBS data base are currently being

Table 4. *Frequency of encounters of coastal and wetlands species on Christmas Bird Count and the Breeding Bird Survey.*

	Christmas Bird Count (1982–83)		Breeding Bird Survey (1977)	
Species	Total circles	Total birds	Total routes	Total birds
Red-throated loon	161	4,656	0	0
Common loon	384	9,771	114	321
Pied-billed grebe	621	13,803	76	157
Horned grebe	320	10,557	11	29
Red-necked grebe	112	2,708	13	47
Eared grebe	185	52,813	22	443
Western grebe[a]	137	70,078	8	449
Double-crested cormorant	375	139,924	45	379
American bittern	123	411	108	316
Great blue heron	894	26,525	481	1,305
Great egret	242	19,565	83	561
Snowy egret	160	13,974	37	263
Little blue heron	102	5,295	97	645
Tricolored heron	97	4,751	18	109
Cattle egret	138	35,426	149	5,582
Green-backed heron	182	1,650	493	1,158
Black-crowned night-heron	226	8,530	51	202
Tundra swan	171	55,018	0	0
Mute swan	122	4,486	3	15
Snow goose (white)	207	973,524	0	0
Snow goose (blue)	118	245,815	0	0
Canada goose	825	1,315,990	92	1,621
Wood duck	410	7,860	160	475
Green-winged teal	484	170,066	41	135
American black duck	567	151,686	54	234
Mallard	1,156	1,577,194	438	5,470
Northern pintail	469	743,705	62	636
Blue-winged teal	168	9,292	150	1,313
Northern shoveler	349	154,089	53	320
Gadwall	530	75,585	60	642
American wigeon	526	381,199	52	282
Canvasback	381	120,135	24	122
Redhead	313	40,026	35	234
Ring-necked duck	523	45,729	9	25
Greater scaup	253	156,303	1	10
Lesser scaup	541	115,772	41	830
Oldsquaw	203	176,165	1	31
Black scoter	150	14,528	0	0
Surf scoter	157	62,552	1	20
White-winged scoter	192	42,401	2	80
Common goldeneye	752	92,937	23	84
Barrow's goldeneye	106	6,688	6	23
Bufflehead	628	77,522	13	70
Hooded merganser	508	10,649	8	31
Common merganser	623	119,841	36	97
Red-breasted merganser	408	67,616	6	12
Ruddy duck	413	154,634	3	549
Osprey	109	1,479	61	104
Bald eagle				
adult	428	4,308	12	20
immature	289	4,965	—	—
age unknown	54	768	—	—

Table 4. *Continued.*

Species	Christmas Bird Count (1982–83) Total circles	Christmas Bird Count (1982–83) Total birds	Breeding Bird Survey (1977) Total routes	Breeding Bird Survey (1977) Total birds
Virginia rail	192	1,063	17	24
Sora	138	956	75	285
Common moorhen	157	10,337	21	131
American coot	657	451,716	112	1,747
Black-bellied plover	173	26,095	0	0
Greater yellowlegs	220	4,446	6	24
Lesser yellowlegs	131	2,492	21	165
Willet	103	34,611	69	573
Spotted sandpiper	196	1,660	203	441
Ruddy turnstone	118	7,538	0	0
Sanderling	167	38,156	0	0
Western sandpiper	143	103,135	0	0
Least sandpiper	207	47,906	2	2
Dunlin	211	192,570	1	1
Long-billed dowitcher	105	20,139	0	0
Common snipe	559	9,004	249	1,394
American woodcock	140	481	36	65
Laughing gull	105	148,781	33	831
Bonaparte's gull	282	139,919	4	31
Ring-billed gull	758	829,705	110	2,929
California gull	123	88,128	32	1,156
Herring gull	725	893,756	129	3,529
Iceland gull	91	6,600	0	0
Kumlien's gull	17	85	0	0
Glaucous-winged gull	101	138,918	11	672
Glaucous gull	143	1,232	1	160
Great black-backed gull	289	104,018	35	296
Forster's tern	156	16,882	24	115
Belted kingfisher	1,027	11,478	462	718
Marsh wren	341	5,680	85	355
Swamp sparrow	617	24,661	278	811

[a] Includes Clark's grebe.

Table 5. *Species frequently encountered on the Breeding Bird Survey and the Christmas Bird Count.*

Breeding Bird Survey (data from 1977)

Encounters	Number of species	Number of species BBS > 1/2 × CBC[a]
20–49	84	48
50–99	62	45
100+	176	148
20+	322	241

Christmas Bird Count (data from winter 1982–83)

Encounters	Number of species	Number of species CBC > 2 × BBS[a]
20–39	57	33
40–99	100	58
100–199	73	41
200+	132	78
20+	362	210

[a] This column is meant to indicate which species are better covered by the BBS and which by the CBC. Because the BBS is better standardized than the CBC, a species is considered better covered by the CBC only when it is encountered twice as frequently on the CBC as on the BBS.

recalculated each year; thus, when the CBC analyses can be done, we will have an unprecedented amount of quantitative information on the population status and trends of North American birds. This information will be of tremendous value for establishing priorities for North American bird conservation. In addition, the data will prove useful in improving our understanding of the population biology of North American birds.

Acknowledgments

The Christmas Bird Count Population Project at Cornell has been generously supported by J. KixMiller, G. W. Knight, N. B. Delavan Foundation, E. I. du Pont de Nemours and Company, Exxon Corporation, FMC Corporation, IBM Corporation, Johnson Foundation (Trust), MARS Inc., Merck Family Fund, Williams Companies Foundation Inc., and many others. J. Lowe helped with data improvements and summaries; he prepared the figures. T. Engstrom, S. Droege, J. Trapp, and an anonymous reviewer helped to improve the manuscript. In addition, I would like to thank the many CBC volunteers who collected, recorded, and edited the data; the National Audubon Society and the staff of *American Birds* who coordinate the CBC and publish the results; and C. Bock and J. Shipman, who provided computerized CBC data.

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Description of the Wisconsin Checklist Project

by

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Introduction

A birding checklist is a simple record of the species of birds that a field observer found at a particular place and time. This form of record-keeping has long been a standard practice among American bird watchers (Hickey 1943). Checklists have traditionally provided information on geographic ranges and seasonal occurrences of migrants. Only recently have checklists been used to monitor temporal and spatial variation in the abundance of birds (Temple and Temple 1976). In theory, when many observers in an area keep concurrent checklist records, their checklists will differ because of differences in the abundance of species and in observer effort. Some species will be reported on every observer's checklist, whereas other species will occur on those of only a few observers. The reporting frequency for each species in an area can be calculated as the percentage of checklists on which the species has been reported. Reporting frequencies are assumed to be primarily a function of each species' relative abundance. A high reporting frequency indicates that a species is relatively abundant, whereas a low reporting frequency indicates that a species is relatively uncommon.

To test whether or not an analysis of systematically maintained checklist records could actually be used to monitor variations in the abundance and distribution of bird species, the Wisconsin Society for Ornithology (WSO), under the guidance of S. A. Temple, began the Wisconsin Checklist Project in 1982 (Temple 1982). This paper described the details of how the Wisconsin Checklist Project operated and summarized briefly some of the project's major accomplishments.

Data Collection

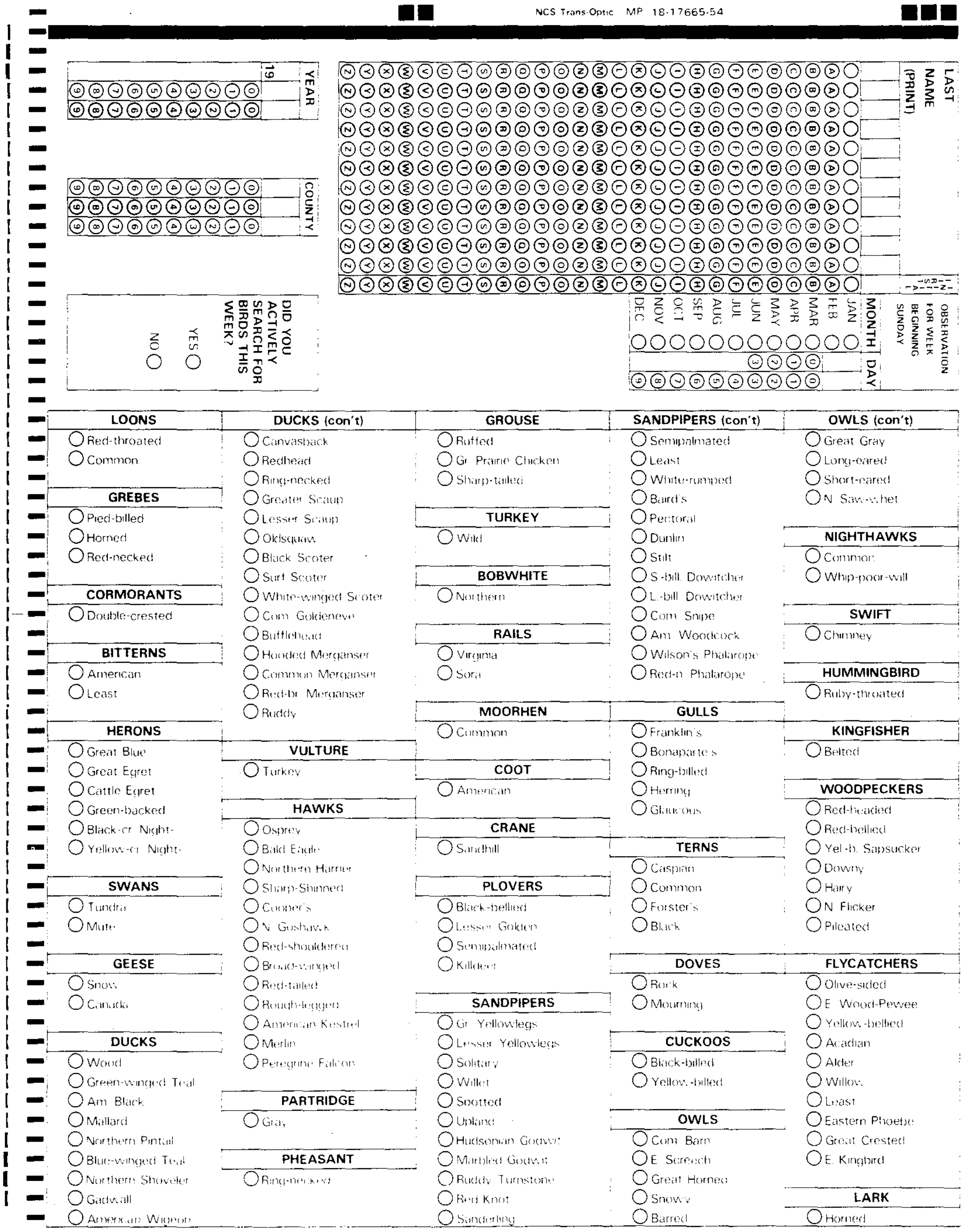
The first and most important requirement for using checklist records to monitor bird populations is a group of reliable and competent field observers who are willing to maintain systematic records. In Wisconsin, many such skilled individuals are members of the WSO, an organization with a long tradition of volunteer participation in ornithological research programs. In response to the call for participants (Temple 1982), 431 of the approximately 1,200 WSO members have volunteered to take part in the Wisconsin Checklist Project. Of these volunteers, 257 have been regular contributors to the project; some have submitted records for every reporting period since the project began.

We asked participants to keep careful records of the bird species that they detected during each week of the year and in which county they had observed them. We provided them with special forms on which to record information for each week (Fig. 1). These forms are designed so that information recorded on them can be read directly by an optical scanning device. This innovation made it possible for us to transfer large amounts of information rapidly and easily from the forms to magnetic tapes and disks that could then be used by computers.

On the weekly reporting forms, participants identified themselves and provided information on the county in which they birded during the recording week, the date of the Sunday that began the recording week, and the level of intensity with which they searched for birds. They then indicated which of 265 bird species they had detected during the week by filling in the "bubble" adjacent to the bird's name. They were not asked to provide any assessment, either objective or subjective, of the abundance of the birds they detected. Completed forms were submitted for annual analysis. Since the project began in 1982 we have received more than 30,000 weekly checklist forms – about 6,000 forms each year.

Analysis of Records

After the forms were scanned and the information converted to a computer-accessible format, we checked records for accuracy. We looked for



NCS Trans-Optic MP 18-17665-54

LAST NAME (PRINT)

FIRST INITIAL

YEAR 19

COUNTY

OBSERVATION FOR WEEK BEGINNING SUNDAY

MONTH
○ JAN
○ FEB
○ MAR
○ APR
○ MAY
○ JUN
○ JUL
○ AUG
○ SEP
○ OCT
○ NOV
○ DEC

DAY

DID YOU ACTIVELY SEARCH FOR BIRDS THIS WEEK?
YES ○
NO ○

LOONS
○ Red-throated
○ Common

GREBES
○ Pied-billed
○ Horned
○ Red-necked

CORMORANTS
○ Double-crested

BITTERNS
○ American
○ Least

HERONS
○ Great Blue
○ Great Egret
○ Cattle Egret
○ Green-backed
○ Black-cr. Night-
○ Yellow-cr. Night-

SWANS
○ Tundra
○ Mute

GEESE
○ Snow
○ Canada

DUCKS
○ Wood
○ Green-winged Teal
○ Am. Black
○ Mallard
○ Northern Pintail
○ Blue-winged Teal
○ Northern Shoveler
○ Gadwall
○ American Wigeon

DUCKS (con't)
○ Canvasback
○ Redhead
○ Ring-necked
○ Greater Scaup
○ Lesser Scaup
○ Oldsquaw
○ Black Scoter
○ Surf Scoter
○ White-winged Scoter
○ Com. Goldeneye
○ Bufflehead
○ Hooded Merganser
○ Common Merganser
○ Red-br. Merganser
○ Ruddy

VULTURE
○ Turkey

HAWKS
○ Osprey
○ Bald Eagle
○ Northern Harrier
○ Sharp-Shinned
○ Cooper's
○ N. Goshawk
○ Red-shouldered
○ Broad-winged
○ Red-tailed
○ Rough-legged
○ American Kestrel
○ Merlin
○ Peregrine Falcon

PARTRIDGE
○ Gray

PHEASANT
○ Ring-necked

GROUSE
○ Ruffed
○ Gr. Prarie Chicken
○ Sharp-tailed

TURKEY
○ Wild

BOBWHITE
○ Northern

RAILS
○ Virginia
○ Sora

MOORHEN
○ Common

COOT
○ American

CRANE
○ Sandhill

PLOVERS
○ Black-bellied
○ Lesser Golden
○ Semipalmated
○ Killdeer

SANDPIPERS
○ Gr. Yellowlegs
○ Lesser Yellowlegs
○ Solitary
○ Willet
○ Spotted
○ Upland
○ Hudsonian Godwit
○ Marbled Godwit
○ Ruddy Turnstone
○ Red Knot
○ Sanderling

SANDPIPERS (con't)
○ Semipalmated
○ Least
○ White-rumped
○ Baird's
○ Pectoral
○ Dunlin
○ Stilt
○ S.-bill. Dowitcher
○ L.-bill. Dowitcher
○ Com. Snipe
○ Am. Woodcock
○ Wilson's Phalarope
○ Red-n. Phalarope

GULLS
○ Franklin's
○ Bonaparte's
○ Ring-billed
○ Herring
○ Glaucous

TERNS
○ Caspian
○ Common
○ Forster's
○ Black

DOVES
○ Rock
○ Mourning

CUCKOOS
○ Black-billed
○ Yellow-billed

OWLS
○ Com. Barn
○ E. Screech
○ Great Horned
○ Snowy
○ Barred

OWLS (con't)
○ Great Gray
○ Long-eared
○ Short-eared
○ N. Saw-whet

NIGHTHAWKS
○ Common
○ Whip-poor-will

SWIFT
○ Chimney

HUMMINGBIRD
○ Ruby-throated

KINGFISHER
○ Belted

WOODPECKERS
○ Red-headed
○ Red-bellied
○ Yel.-b. Sapsucker
○ Downy
○ Hairy
○ N. Flicker
○ Pileated

FLYCATCHERS
○ Olive-sided
○ E. Wood-Pewee
○ Yellow-bellied
○ Acadian
○ Alder
○ Willow
○ Least
○ Eastern Phoebe
○ Great Crested
○ E. Kingbird

LARK
○ Horned

Fig. 1. A sample of the optically-scannable checklist form on which volunteers recorded their observations.

misspellings of an observer's name, erroneous dates for the start of the recording week, nonexistent county codes, and highly improbable reports of a bird species outside of its normal range or season of occurrence in the State. Errors of the last type were of most concern to us, and when they were found, we deleted them from subsequent analysis. Over the first 5 years of the project we caught 78 such suspicious records. Most of those seemed to have been simply the result of a participant accidentally filling in the wrong bubble on the form. For example, we looked on with suspicion and deleted a July record of a gray jay (*Perisoreus canadensis*) from a southern Wisconsin county (far beyond the jay's normal range), especially because during that week the observer had failed to report a blue jay (*Cyanocitta cristata*; the region's common jay). The two jay species appear next to one another on the checklist form, so we suspected a simple slip of the pen. To double-check the accuracy of the data, we also prepared yearly summaries of each participant's reports and returned these summaries to the participant for review. This review process allowed the original observer to help us further in detecting and correcting erroneous records.

Our analyses of the edited data followed several paths. In order to detect seasonal variation in abundance of birds in the State, we calculated weekly reporting frequencies for each species. Results of this type of analysis have been presented by Temple and Temple (1984) and Temple and Cary (1987a). An example is shown in Fig. 2.

In order to detect geographical variation in the abundance of birds, we divided the State into 43 regions, each of which included an adequate number of observers and checklists. We calculated each species' reporting frequency in each region over a specified period, such as the breeding season or the entire year. Temple and Temple (1987) and Temple and Cary (1987b) presented some preliminary results of these types of analyses. An expanded analysis of trends in relative abundance revealed by the checklist records is included elsewhere in this volume (Temple and Cary 1990). An example is shown in Fig. 3.

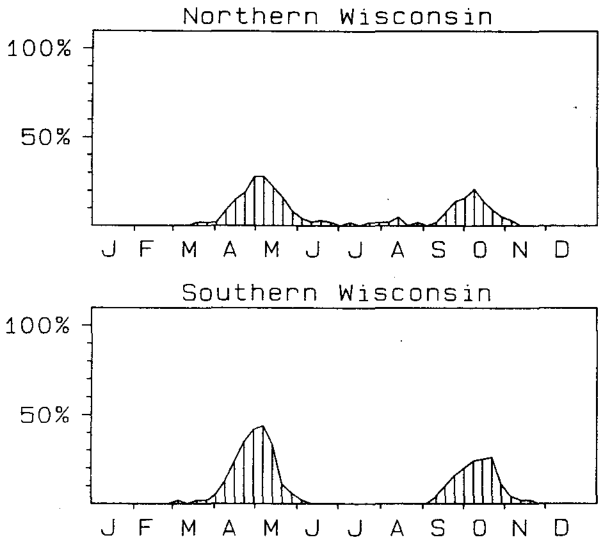


Fig. 2. An example of the seasonal variation in abundance of the ruby-crowned kinglet (*Regulus satrapa*) keep in Wisconsin, as revealed by an analysis of checklist records.

Important Assumptions

The Wisconsin Checklist Project is based on a number of assumptions that underlie the use of the data to detect variations in abundance.

- Volunteer observers are accurate in their reporting habits, following instructions rigidly and doing their best to optimize their efforts to detect birds.
- Reporting frequencies are a function of the relative abundance of birds. Temple and Cary (1990) address this assumption later in this volume.
- Reporting frequencies are more affected by changes in abundance than they are by other factors (e.g., the behaviors of birds or observers) because of the dynamic mixing of these other effects.
- At least over the short term, the efforts of the observers remain relatively similar between years (i.e., their birding habits and skills change slowly).

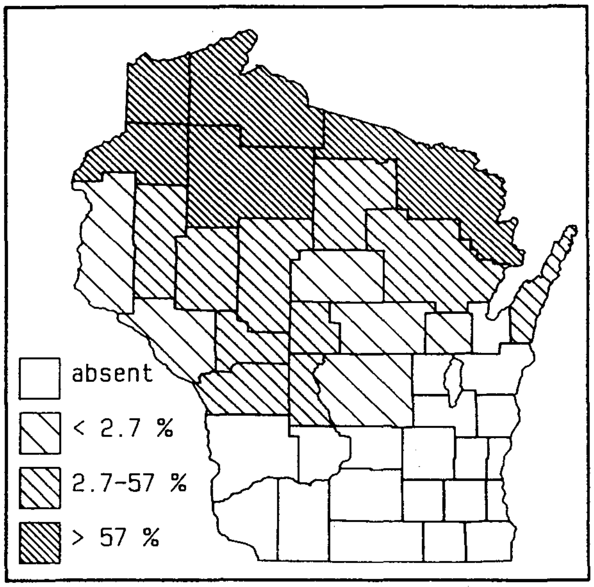


Fig. 3. An example of the geographic pattern of relative abundance of the common raven (*Corvus corax*) keep, as revealed by an analysis of checklist records; *shading* categories portray reporting frequencies.

Conclusions

Our experiences with the Wisconsin Checklist Project convince us that the approach has considerable merit. The technique is readily accepted by volunteer cooperators, and it produces interpretable data reflecting seasonal, geographic, and year-to-year variations in bird populations. Temple and Cary (1987a) produced a book that presented many of the results of the project in a format that has proved useful and appealing to bird watchers, thus demonstrating to volunteers that their efforts have been worthwhile.

Acknowledgments

We are grateful to the 431 members of the Wisconsin Society for Ornithology who have submitted checklist records during the first 5 years of the Wisconsin Checklist Project. A. J. Temple kept track of these volunteers and the nearly 30,000 checklists they submitted for analysis. The Wisconsin Checklist Project received financial support from the A. W. Schorger Fund of the Department of Wildlife Ecology, University of Wisconsin – Madison.

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Use of Breeding Bird Atlases to Monitor Population Change

by

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Introduction

Breeding Bird Atlases are cooperative projects designed to map the breeding distributions of all species of birds within a prescribed area, such as a county, a Nation, or even a continent, within a defined period of years. Mapping is done using a grid of usually 5 or 10 km, and either every block in the grid or a random or systematic sample of blocks is visited, with the intent of recording presence or absence of each species during the nesting season. Primary emphasis is on determining if a species is present and assigning the highest category of nesting evidence: Possible, Probable, or Confirmed. The categories of evidence under each of these three terms were defined in the first major grid-based avian atlas (Sharrock 1976), endorsed with minor alterations by the European Ornithological Atlas Committee in 1974, and accepted, again with very minor alterations, by the Northeastern Breeding Bird Atlas Conference in Woodstock, Vermont, in 1981, and by the North American Ornithological Atlas Committee in 1987.

The original purposes of Breeding Bird Atlases were to map breeding distribution on a fine scale in such a way that future expansions and contractions of range could be documented. Additional benefits identified with the early atlases were: discovery of ecologically rich or unique habitats that deserve preservation, location of new sites for rare and endangered species, accumulation of a data base for further research, and provision of a useful and exciting project that would involve amateur birders during a season when they often are not heavily involved with other birding activities.

History

The concept of grid-based natural history atlases originated in the British Isles with the publication in 1962 of Perring and Walters' atlas of the British flora, which used the national 10-km grid. The Biological Records Centre, Abbots Ripton, England, subsequently promoted the systematic mapping of flora and fauna throughout the British Isles and assisted many other European countries in initiating atlas projects.

After a trial avian atlas project in three British counties (Lord and Munns 1970), the British Trust for Ornithology undertook a 5-year atlas of breeding birds in Britain and Ireland (Sharrock 1976). This was a tremendous effort that included visits to all 3,862 10-km blocks in the British Isles and involved more than 10,000 participants. Not only did this atlas provide direct comparisons with the botanical atlas, but also the bird atlas came with 12 habitat and climatic overlays that greatly assisted interpretation of the bird distribution maps.

The European Ornithological Atlas Committee was formed in 1971 to standardize methodology and provide assistance to other Nations. This committee adopted standardized codes in 1972. During the next decade national atlases were published for France, Denmark, West Germany, Netherlands, and Switzerland, as well as regional atlases for parts of England, Germany, and Spain. At least two African atlases have been published (Cyrus and Robson 1980; Nikolaus 1987) as well as a national atlas for New Zealand (Bull et al. 1985), a national atlas for Australia (Blakers et al. 1984), and some more-detailed regional atlases for parts of Australia (Thomas 1979; Emerson et al. 1987).

Atlasing in the United States began with a preliminary mapping of bird distribution in Montana by its 47 one-degree blocks of latitude and longitude (Skaar 1975). In the same year R. Stewart (1975) published a much more detailed book on North Dakota breeding birds based on townships (6 × 6 mi = about 9.7-km grid); although he did not use atlas categories and procedures, he personally visited nearly all townships in the State and mapped every breeding species by township. The first published North American atlas to use the standard atlas codes and procedures was of two adjacent counties in Maryland (Klimkiewicz and Solem 1978). Currently, State and Provincial atlases have been published for Maine (Adamus 1988), New York (Andrle and Carroll 1988), Ontario (Cadman et al. 1988), and Vermont (Laughlin and Kibbe 1985). Atlas projects are in progress or completed for several Western States, all Canadian Provinces, and for all States east of the Mississippi River except Mississippi, Alabama, South Carolina, and Wisconsin. For more details on the history of atlasing see Robbins (1982).

Procedures

Organization and Recording Forms

Most atlas projects are sponsored by a State or provincial ornithological or Audubon society in collaboration with the conservation department. In most States there is a full-time salaried State coordinator for the duration of the fieldwork and manuscript preparation. A network of volunteer county coordinators solicits, trains, and encourages cooperators as work progresses.

Participants are supplied with a map of their block and a handbook. The handbook contains instructions, explains codes, and often includes a table of "safe dates" during which one can assume birds of that species are on nesting territory. Definitions for all the codes are given in Sharrock (1976), Laughlin (1982), and the *North American Atlas Handbook* (Smith, in preparation). Newsletters are mailed to participants once or twice each year to maintain their interest by reporting progress, providing helpful suggestions, and cautioning against common errors.

Forms vary from project to project because each State or Province has its own list of breeding species. The field cards have columns for the Possible, Probable, and Confirmed codes. Generally there is an annual summary sheet that is appropriately coded for data entry. Some States and Provinces have additional columns for numerical estimates, dates of observations, or quarter-block designation.

Grid Size

The original 10-km grid of the British Isles was adopted in much of western Europe except in the small countries, which used a 5-km grid, and in countries such as France, Spain, and Portugal, which had national topographic maps to their own unique scales. Canada adopted a 10-km grid, but most of the eastern United States has used a close approximation to a 5-km grid. In many northeastern States (Connecticut, Delaware, Maryland, Massachusetts, New York, Pennsylvania, and Rhode Island) every 5-km block is visited. In others (Illinois, New Hampshire, Vermont, Virginia, West Virginia, and many others), a random or systematic sample of blocks is visited. In addition, some other blocks are targeted for special biological or political reasons, but this special set is not included in the statistical summary of results. A few States (Maine and Texas) are using entire 7.5-min topographic maps as their grid; but using such a coarse scale will make it difficult to detect future changes. Even if 90% of the habitat in a block were to disappear, the remaining 10% probably would retain at least one pair of most or all of the original species. For this reason, the *North American Breeding Bird Atlas Handbook* recommends a 5-km grid for the United States, even if this means covering only a sample of atlas blocks instead of all of them. A random or systematic sample of 2.5-km quarter-blocks is recommended to enhance opportunities of detecting future changes or to correlate bird distribution with other environmental variables. Quarter-blocks are discussed further in connection with applications.

Field Techniques

Participants are urged to study their topographic map and to visit all habitats that occur in their block. They are urged to concentrate their fieldwork in the early morning when most species reach their peak of activity. Participants also are encouraged to make some nocturnal trips for species that are most active at night. Initial efforts are to record as many species as possible. On subsequent trips an attempt is made to upgrade each species from Possible to Probable status or from Probable to Confirmed. Most observers continue to visit their block until additional trips provide few new species and few upgrades of status.

Observers are encouraged to keep working within a block until they have found at least 75% of the expected species. Coordinators in many States try to estimate the number of species that occur in each block, or at least an average number for the State or Province. Some States have a goal of getting confirmation for 50% of the species recorded in each block; other States have put more emphasis on Probable records and try to get 75% of the species into Probable or Confirmed status. For much of the East there has been a goal of 70 or 75 species, with no more than a quarter of these in Possible status.

Some atlas projects have set a minimum goal of 16 h of coverage. Because of differences in observer expertise, either a species goal or reaching the limit of one's competence (failing to add other species or to achieve additional upgrades) seems more realistic.

Numerical Estimates

There is no compulsory procedure for estimating the number of birds of each species within atlas blocks. The

North American Breeding Bird Atlas Handbook (Smith, in preparation) lists various methods that have been used. For the United States and southern Canada, Breeding Bird Survey (BBS) data for the more common species give index values by physiographic regions within each State and Province. These indices should provide better comparisons with future years than estimates of actual numbers made by unskilled amateurs.

Miniroutes (Bystrak 1980) were developed specifically for adding a quantitative dimension to atlas studies. These are abbreviated BBS routes of 15 to 25 standardized 3-min counts at half-mile intervals along secondary roads. The counts must be made by experienced observers who are familiar with songs and calls of all species likely to be encountered. When miniroutes are run in all blocks or in a specified sample of atlas blocks, they can provide an index of either abundance or distribution (depending on whether birds are counted or just checked for presence and absence). For a discussion of application of miniroutes see Robbins and Dowell (1986).

The atlases of France (Yeatman 1976) and Ontario (Cadman et al. 1988) have used observer estimates of number of pairs of each species in each block. These estimates are made in powers of 10: 1, 2–10, 11–100, 101–1,000, and so forth. The estimates required considerable interaction between coordinators and observers because of a strong tendency to underestimate the number of birds in an atlas block.

The British, in their winter atlas (Lack 1986), successfully used actual counts obtained per 6 h of fieldwork in winter, and these counts were adjusted by use of a conspicuousness factor that was generated for each species. So far, no similar procedure has been tried in North America.

Editing and Computerization

Records are submitted annually at the close of the breeding season, through the county coordinators to the atlas coordinator, for critical review before data entry. After computer editing, listings and maps are prepared and the data reviewed again at various levels. After fieldwork is completed, species accounts to accompany the maps are written by selected authors.

Standardization

General procedures, including codes and terminology, have been fairly well standardized from the beginning. With a few exceptions the grid used has been close to 10 km or 5 km, depending largely on the size of the country, State, or Province. However, it has not been feasible to adopt the Universal Transverse Mercator (UTM) grid worldwide, as some had hoped. The number of years of fieldwork has usually been 5 or 6.

So far, numerical treatment has not been standardized. In some countries extensive bird population information from other sources, such as counts of colonial waterbirds or breeding densities by habitats, has been incorporated into the atlas book. At the other extreme, some atlases have made no attempt to present numerical data beyond the percentage of blocks with each species.

The text accompanying the atlas maps differs widely in scope and content, ranging from no species text at all in the Maine atlas to major State bird books that include all species (not just breeding birds) in Delaware and Massachusetts (in various stages of compilation).

Applications

Mapping Range Expansions and Contractions

This continues to be one of the major objectives of atlas programs. Atlas work already has demonstrated the potential for showing changes in breeding distribution at the county as well as the State level. In Maryland, for example, the 1983–87 atlas showed major changes in many species from the range maps published by Stewart and Robbins (1958). These changes included more than doubling of the Maryland breeding range of the tree swallow (*Tachycineta bicolor*), fish crow (*Corvus ossifragus*), golden-crowned kinglet (*Regulus satrapa*), veery (*Catharus fuscescens*), Nashville warbler (*Vermivora ruficapilla*), blue-winged warbler (*V. pinus*), and swamp sparrow (*Melospiza georgiana*); substantial increases in breeding range of the mallard (*Anas platyrhynchos*), black vulture (*Coragyps atratus*), cliff swallow (*Hirundo pyrrhonota*), and blue grosbeak (*Guiraca caerulea*); and extirpation of the yellow-bellied sapsucker (*Sphyrapicus varius*), Bewick's wren (*Thryomanes bewickii*), Bachman's sparrow (*Aimophila aestivalis*), and the native peregrine falcon (*Falco peregrinus*). In addition, the Canada goose (*Branta canadensis*) and the house finch (*Carpodacus mexicanus*), unknown as Maryland breeders in the 1950's, now nest in almost every county.

Detecting and Monitoring Population Changes

The BBS does a great job of monitoring the common roadside species by major regions of the continent, but it cannot be depended on at the county level, where sample sizes are too small.

The two atlases of Howard County, Maryland, have demonstrated that even over a period as short as 10 years (1973–75 to 1983–87) many changes in bird distribution and abundance occur, and these can easily be detected with a quarter-block (2.5-km) grid, even without the use of numerical counts. It is hard to obtain a meaningful estimate of the number of hours spent on atlas fieldwork, especially when atlasers reside in the block to which they are assigned, or make casual observations on the way to work each day. Thus, total hours reported spent on atlasing is not as good a basis for comparison over a period of years as the sum of the bird lists for all atlas blocks in the county. In the Howard County example, the total number of records (sum of the species lists) for the 136 quarter-blocks in 1973–75 was 8,297, compared to 9,683 for 1983–87, a 16.7% increase. This increase in efficiency of coverage (1.167) was multiplied by the number of blocks in which a species was recorded during the first atlas period to obtain an estimate of the expected number of blocks for the second period, assuming no change in population. A major departure from this estimate indicates an increase or decrease in the local population of the species in question. Thirty-four Howard County species showed significant changes by chi-square tests ($P < 0.05$); a few of these are shown in the Table. The entire list appears in *Acta Zoologica Fennica* (Robbins et al. 1989).

By breaking a county into regions, or by combining data from several nearby counties, one can apply nonparametric statistics and assign confidence limits to the probability of change. Use of miniroutes, which is recommended in the *North American Breeding Bird Atlas Handbook* (Smith, in preparation), will further increase the potential for detecting changes within a State, Province, or county.

Other Applications

There are many other applications of atlas data that were not conceived when atlas programs began. These include:

- documenting the effects of habitat fragmentation,
- defining boundaries of ecological regions (bird districts) on the basis of their bird populations,
- land use planning so as to preserve areas of special conservation value,
- detailed correlation of bird distribution with forest cover types and other forms of land use,
- compilation of automated data banks that can be used for a multitude of research and conservation applications,
- providing an impartial means of defining rarity, and
- combining data from many adjacent States and Provinces to obtain a larger perspective on current population status and on changes in distribution and abundance.

The Future

Atlasing has proven to be extremely popular among tens of thousands of amateurs, who give freely of their time and expertise. Not only are many of the most sophisticated amateurs in North America contributing their talents, but also they are training countless

Table. *Changes in number of quarter-blocks in Howard County, Maryland, where selected species were detected in 1973–75 and 1983–87. Expected values for 1983–87 are 1.167 times the 1973–75 values, representing the increase in total number of records received.*

Species	1973–75 Observed	1983–87 Expected	1983–87 Observed	Change (%)
Increases				
Canada goose (*Branta canadensis*)	8	9	46	+411%
Mallard (*Anas platyrhynchos*)	49	57	86	+ 51%
Black vulture (*Coragyps atratus*)	18	21	73	+248%
Pileated woodpecker (*Dryocopus pileatus*)	29	34	86	+153%
Cliff swallow (*Hirundo pyrrhonota*)	6	7	20	+186%
Hooded warbler (*Wilsonia citrina*)	43	50	74	+ 48%
House finch (*Carpodacus mexicanus*)	0	0	129	—
Decreases				
American black duck (*Anas rubripes*)	10	12	3	–75%
Whip-poor-will (*Caprimulgus vociferus*)	30	35	21	–40%
Horned lark (*Eremophila alpestris*)	47	55	18	–67%
Bank swallow (*Riparia riparia*)	9	11	2	–82%
Vesper sparrow (*Pooecetes gramineus*)	51	60	22	–63%
Grasshopper sparrow (*Ammodramus savannarum*)	103	121	78	–36%
Eastern meadowlark (*Sturnella magna*)	126	147	103	–30%

thousands in the techniques of atlasing and are diverting the attention of many birders into serious ornithological data gathering. The rather crude atlasing of today will probably be followed by more sophisticated atlas endeavors in the future, with a more quantitative approach. I expect atlases of the next century to be as much advanced over today's atlas endeavors as today's Christmas Bird Counts are over the initial published Christmas Bird Censuses of the early 1900's.

Acknowledgments

I thank the members of the Howard County Chapter of the Maryland Ornithological Society, especially D. C. Dupree, J. Farrell, M. K. Klimkiewicz, and J. K. Solem, for the intensive atlas coverage of their county during 1973–75 and 1983–87. I also thank S. Droege, J. R. Sauer, and C. R. Smith for their constructive comments on the manuscript.

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Methodology of the International Shorebird Survey and Constraints on Trend Analysis

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Origin and Extent of the Survey

The International Shorebird Survey (ISS), managed by Manomet Bird Observatory (Massachusetts) since 1972, enlists the services of volunteer observers to conduct surveys of migrating shorebirds in the Western Hemisphere (Manomet Bird Observatory 1980). In 1974, the definition of ISS was broadened to include the Maritimes Shorebird Survey (MSS; Morrison 1976) conducted during the 1970's by the Canadian Wildlife Service. However, because of difficulties in obtaining the MSS data, the ISS includes only the Manomet survey for the purposes of the present discussion. The purpose of the ISS has always been to identify and document areas of major importance to shorebirds during fall migration (in recent years some spring surveys have been conducted). The ISS has focused on the eastern United States, especially between Maine and North Carolina, but includes sites as distant as Kansas, the Caribbean, and Latin America.

Design of the Survey

Participants in the ISS are recruited on the basis of recommendations from persons known to be experienced at shorebird identification. In this way, a reasonable level of quality control is assured. Unlike the Breeding Bird Survey and some other surveys, sampling areas in the ISS are not preselected randomly. In part, this is because the survey was not designed to obtain estimates of population change. Furthermore, the difficulty of access to many wetland habitats used by shorebirds makes random selection impractical. Observers are encouraged to select sites on the basis of traditional shorebird use and convenience of access. A special effort is made to ensure coverage of sites known to attract large numbers of shorebirds every year. Observers are asked to define the limits of the survey site and visit it at least three times per month between 1 July and 31 October, the period that encompasses the majority of the migration period for most species. Few observers achieve such intensive coverage, however, and many sites are surveyed only a few times annually or missed entirely in some years. The total number of each species is determined by either direct count or subjective estimation and coded appropriately. In tidal areas there is an effort to conduct the survey during the same segment of the tide cycle to minimize the influence of local movements in response to tide fluctuations. Each survey is summarized on forms provided by Manomet Bird Observatory. The forms are then checked and edited by Manomet staff, and the data are computerized.

To date, more than 600 volunteers have collected data for the ISS at more than 500 sites in the United States. Annually, an average of 1,500 surveys at 150 sites has been conducted. Because turnover rates of migrating birds at different sites are poorly known, it is difficult to estimate the total number of shorebirds censused annually. In a recent analysis of only 64 Atlantic coastal sites, the minimum annual estimate (assuming no turnover) for the commonest species, the semipalmated sandpiper (*Calidris pusilla*), was 34,500 (Howe et al. 1989). The actual number observed at this subset of sites was probably 3–4 times this number.

International Shorebird Survey sampling design and certain properties of the data present difficulties for population trend estimation. I summarize those difficulties and evaluate the degree to which they can be overcome. Some of these issues are addressed in more detail elsewhere (Howe et al. 1989).

Problems Associated with Sampling Design

To be suitable for trend analysis, the data must meet the assumption that the birds sampled are representative of the total population or some definable subset. Although the nonrandom distribution of ISS sites threatens this assumption, there are potentially more serious problems. For example, many species prefer inland, freshwater sites, opportunistically selecting wetlands that have suitable water conditions at any given time. Also, the number of ISS sites is limited, and the influence of major stopovers not included in the network is unknown.

Finally, during migration, shorebirds move through stopover sites at varying rates determined by physiological and climatological factors. Major flights could be overlooked if the interval between samples is too long. All of these factors potentially influence the accuracy and precision of ISS counts, introducing variation that is independent of true population change.

By accepting certain assumptions and using the ISS data least sensitive to the sources of variation listed previously, it seems that these concerns can be minimized. In a preliminary study (Howe et al. 1989) we confined trend analyses to a subset of 12 species we believe to be obligate users of coastal habitats (eliminating opportunistic species) and examined only ISS sites on the Atlantic coast. We felt that this approach would reduce the risk of overlooking major segments of the population. Concern about the nonrandom distribution of sites is allayed somewhat by our present knowledge of the ecology of migrating shorebirds. Several studies (e.g., Smith and Houghton 1984; B. A. Harrington, unpublished data) showed that at least some individuals of some species showed between-year fidelity to migration stopovers. Also, many stopover sites attract large numbers of shorebirds annually. If traditional use of these sites is the rule for many species of shorebirds, our confidence in the sample counts as indicators of true population trends is greatly increased.

With regard to the temporal aspect of migration, analysis of ISS data shows that most species exhibit fairly sharp population peaks. If none of the samples occurs during the peak period, the populations for that site will be seriously underestimated. Several studies of semipalmated sandpipers (Page and Middleton 1972; Lank 1983; Dunn et al. 1988) suggested that, early in southbound migration, lengths of stay of individual birds at stopovers averaged 2 to 3 weeks. If we assume this is typical of migrating shorebirds, a regime of sampling at 10-day intervals should on average yield one to three counts during the peak period.

Problems Associated with Data Structure

Conducting route-regression trend analysis (Geissler and Noon 1981) requires a single count representing the population at a given site in a given year. Some ISS sites may have several dozen censuses conducted during a year, covering a period in which populations may fluctuate dramatically. These counts must be converted to one value representing an annual site index. We examined four approaches to calculating site indices and determined that the best measure was the log of the average of all counts within a 21-day period centered at the regional migration peak (Howe et al. 1989). Sites with less than two counts during that period were eliminated from analysis. This approach yielded the smallest variances for population trend estimates. All indices that incorporated data from both peak and nonpeak periods yielded extraordinarily high variances.

Even the best population index yielded within-site variances much higher than those typical of surveys like the BBS, which samples populations that are more or less uniformly distributed in space and time. This is a potential problem for trend analysis because of the importance of the variance in the back-transformation from the log scale. However, analyses of simulated data sets with comparably high variances yielded trend estimates not significantly different from the trends assumed for the simulation (Howe et al. 1989). This is an encouraging sign, suggesting that the variance problem may not be critical.

A final concern about the ISS data set analyzed for 1972–83 was the large number of site-year combinations for which data were unavailable. This situation could result in certain years contributing disproportionately to the trend estimate. We analyzed the entire data set for the sanderling (*C. alba*), which was recorded at an average of 52 sites each year, and found that all possible pairs of years were uniformly represented despite the spotty coverage. Inconsistent coverage in the future, however, could occasionally lead to biases toward certain years and produce erroneous trend estimates.

Conclusions

The International Shorebird Survey, though not rigorously designed to monitor shorebird populations, produces data that can presently be used to derive imprecise population trend estimates for obligate coastal species. It is unlikely that species that often use transitory wetlands during migration can be monitored effectively. For the present, it is assumed that population changes at coastal ISS sites are representative of population changes throughout the coastal system (this assumption is presently being field-tested). Observer variation in estimating the size of large flocks is also a potential problem, the magnitude of which is not known. More precise estimates of population trends could be achieved by increasing the frequency of surveys at the most important sites, particularly during peak periods, and by assuring continuity of coverage across years. Formal incorporation of coastal Canadian sites into the

ISS would help improve population trend estimates for several species.

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Evaluation of the Colonial Bird Register

by

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History of the Colonial Bird Register

In the early 1970's E. J. Fisk and R. Downing started counting least terns (*Sterna antillarum*) along the eastern seaboard because they were concerned that the species was declining (Downing 1973; Fisk 1975). They organized a loose network of volunteers to count terns, although they did not have a standardized system of data collection.

At about the same time, the prospect of offshore oil drilling and increasing human use of coastal habitats in the eastern United States posed threats to wildlife, especially colonial birds. In response to these threats, the U.S. Fish and Wildlife Service initiated surveys of colonial waterbirds on the Great Lakes (Scharf 1979) and along all coastal areas of the United States (Erwin 1979; Erwin and Korschgen 1979; Korschgen 1979; Sowls et al. 1980; Portnoy et al. 1981; Keller et al. 1984; Spendelow and Patton 1988).

A central data repository was an attractive idea when interest in waterbird colonies was high and financial support was available. The surveys of Fisk and Downing provided a model for an organization of volunteers to collect data. The Colonial Bird Register (CBR) was established on 1 August 1975 by joint agreement between the National Audubon Society and the Cornell Laboratory of Ornithology. The CBR relied on a network of volunteer organizations and individuals to contribute data.

From 1975 through 1984, the National Audubon Society paid most of the expenses of the CBR, including the salary of the director. The Cornell Laboratory of Ornithology covered administrative costs and provided office space. Between 1979 and 1986, the U.S. Fish and Wildlife Service also supported the CBR through a series of cooperative agreements. User fees for data retrieval were expected to defray operational costs of the CBR; however, the fees, averaging a few hundred dollars per year, never covered the costs.

CBR Design and Content

One of the first priorities of the CBR was to devise a form to standardize data reporting. This form had to be detailed enough to provide data for a variety of analyses and easy to use. Data categories on the form have been modified twice over the years (McCrimmon 1978; Erwin et al. 1984; Appendix).

The latest CBR form (Appendix) has space for information on the date of colony visit, colony location, habitat, colony disturbances, colony-site ownership and management, survey technique, and nesting stage. The vehicle from which birds are counted (e.g., airplane, helicopter, boat) is also recorded.

The CBR contains data on locations and estimates of abundance for gull, tern, heron, and egret colonies, some of which are composed of several species (McCrimmon 1978; Erwin et al. 1984). A single record is made for each visit to a colony, although a colony may be visited more than once in a year. An estimate of abundance for each colony can be a count of active nests, adults, or the number of breeding pairs. Records for 48 colonial seabird and wading bird species are included in the CBR (Table). The CBR also contains records for some swallows and more than 30 noncolonial species counted incidentally among truly colonial species.

Data are edited and entered into the computerized data base, which is in the ISIS data base management system on the Cornell University mainframe computer. Data can be retrieved by various geographical divisions (e.g., colony, county, State) or by species.

CBR data come primarily from State wildlife agencies, the U.S. Fish and Wildlife Service, and private organizations such as The Nature Conservancy and State Audubon societies. The survey of colonial waterbird colonies from Maine to Florida in 1976 and 1977 forms the foundation of the computerized portion of the CBR (Erwin and Korschgen 1979; Portnoy et al. 1981) – data from Texas from 1973 to 1980 comprise another large portion (Texas Colonial Waterbird

Table. *Names of species included in the Colonial Bird Register (CBR).*

Common	Scientific	CBR records[a]
Leach's storm-petrel	*Oceanodroma leucorhoa*	33
American white pelican	*Pelecanus erythrorhynchos*	133
Brown pelican	*Pelecanus occidentalis*	163
Great cormorant	*Phalacrocorax carbo*	43
Double-crested cormorant	*Phalacrocorax auritus*	862
Olivaceous cormorant	*Phalacrocorax olivaceus*	106
Magnificent frigatebird	*Fregata magnificens*	8
Least bittern	*Ixobrychus exilis*	31
Great blue heron	*Ardea herodias*	4,514
"Great white" heron	*Ardea herodias occidentalis*	40
Great egret	*Casmerodius albus*	2,382
Snowy egret	*Egretta thula*	1,791
Little blue heron	*Egretta caerulea*	1,273
Tricolored heron	*Egretta tricolor*	1,322
Reddish egret	*Egretta rufescens*	459
Cattle egret	*Bubulcus ibis*	1,610
Green-backed heron	*Butorides striatus*	313
Black-crowned night-heron	*Nycticorax nycticorax*	1,708
Yellow-crowned night-heron	*Nycticorax violaceus*	281
White ibis	*Eudocimus albus*	520
Glossy ibis	*Plegadis falcinellus*	395
White-faced ibis	*Plegadis chihi*	413
Roseate spoonbill	*Ajaia ajaja*	333
Wood stork	*Mycteria americana*	152
Common eider	*Somateria mollissima*	483
Black-necked stilt	*Himantopus mexicanus*	27
American avocet	*Recurvirostra americana*	21
Laughing gull	*Larus atricilla*	1,296
Franklin's gull	*Larus pipixcan*	109
Ring-billed gull	*Larus delawarensis*	307
California gull	*Larus californicus*	181
Herring gull	*Larus argentatus*	1,800
Glaucous-winged gull	*Larus glaucescens*	9
Great black-backed gull	*Larus marinus*	980
Gull-billed tern	*Sterna nilotica*	794
Caspian tern	*Sterna caspia*	361
Royal tern	*Sterna maxima*	365
Sandwich tern	*Sterna sandvicensis*	217
Roseate tern	*Sterna dougallii*	216
Common tern	*Sterna hirundo*	2,623
Arctic tern	*Sterna paradisaea*	116
Forster's tern	*Sterna forsteri*	824
Least tern	*Sterna antillarum*	4,097
Sooty tern	*Sterna fuscata*	34
Black tern	*Chlidonias niger*	136
Black skimmer	*Rynchops niger*	1,659
Razorbill	*Alca torda*	7
Black guillemot	*Cepphus grylle*	237
Atlantic puffin	*Fratercula arctica*	11

[a] The number of records over all years. This is not the same as the number of colonies; some colonies were visited more than once in a season.

Society 1982). Most recently, organized counts such as the annual survey of Long Island, New York (MacLean et al. 1988), have generated the most data for the CBR, followed by reports from many national wildlife refuges. The number of records in the CBR ranges from 0 in West Virginia to nearly 2,200 in New York (Fig. 1).

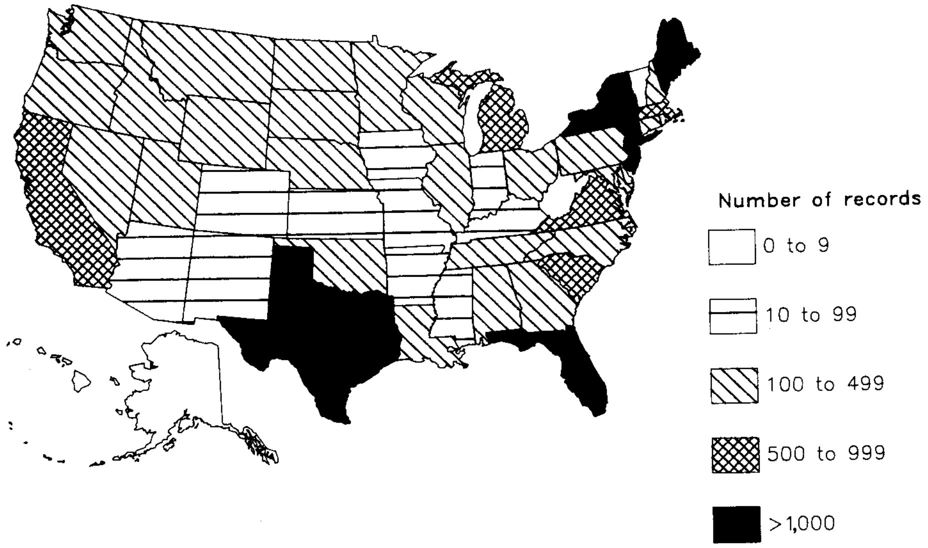

Fig. 1. The number of computerized CBR records of visits to colonies by State. This does not include 263 records from Canada. Some colonies are visited several times in a season.

Coverage among States varies from complete annual surveys of all colonial birds to spotty reporting of only a few colonies. The greatest number of CBR records came from 1976 (3,100) and 1977 (2,600). Data contributions dropped in 1978, and since then average 1,000 to 1,500 records per year (Fig. 2).

Evaluation of the CBR

The CBR was designed to consolidate the results of local and regional colonial waterbird surveys. Accessibility of the data for researchers was a high priority. As data accumulated, examination of population trends became possible (Erwin et al. 1984). Quantitative data must be collected in a consistent way over time for population trend analysis. Usefulness of the CBR depends on the quality and consistency of the monitoring effort and data base accessibility.

Monitoring Effort

The CBR includes data for a heterogeneous group of species from a large geographical area for an indefinite period. The diffuse data aren't extensive for any single purpose, although some species in some regions have enough data for preliminary analysis (Engstrom et al. 1990). Most contributors to the CBR were concerned primarily with bird populations for a

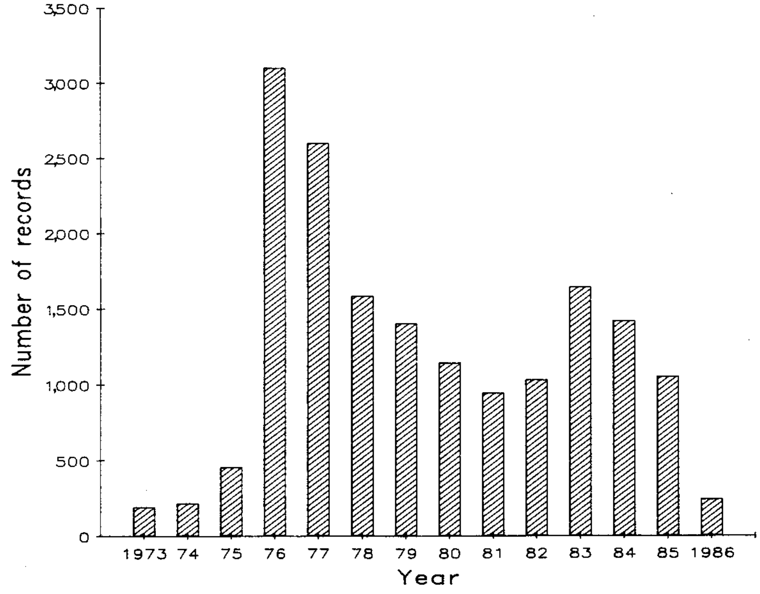

Fig. 2. The number of computerized CBR records by year. Note: only records of least tern colonies are represented in 1986.

single State and used custom-made sampling schemes. The assortment of goals and methods at the State level made the centralized CBR data base a patchwork. The ultimate uses of the data need to be articulated clearly from the origin of the data base (Moroney 1984), then monitoring must adhere to standard practices of data collection and recording.

The technical problems associated with the monitoring effort that supplies the CBR (Erwin et al. 1984) include: (1) observers vary in quality; (2) counting techniques vary among colonies, States, and years; (3) colony names are inconsistent among years and observers; (4) inactive colonies are not recorded as "zeros," making trend analysis problematic; and (5) geographical coverage of colonies varies among States.

The Data Base

Centralization and computerization have made CBR data easily accessible to conservation organizations, academic researchers, and State wildlife management agencies. The data base greatly speeds organization of a wide array of counts and independent studies into regional summaries. Standardized reporting aids comparison of data from different sources, if the forms were filled out completely. Data that were collected by different methods can be compared by using correction factors, although these factors should be used with caution. For example, empirically derived correction factors have been used to compare aerial counts with ground counts (Erwin 1979; Thompson 1982; Engstrom et al. 1990).

Contributors want to see the results of contributing their data to a centralized data base. Products of the CBR, such as an analysis of trends in the population of a species or maps of colony locations, are expensive. Data contributors may be reluctant to go through the burden of filling in standardized forms and then be asked to pay for an analysis of their own data. Additionally, some contributors, especially university biologists, want to protect their data from use by other researchers because they intend to publish their results. In the extreme case, the data base is left in the untenable position of gathering data that cannot be used. This problem can be circumvented by making an agreement between the contributor and the data base to protect the data for a specified time.

Recommendations

1. The goals, methods of analysis, and census or survey guidelines that relate to those goals should be clearly defined at the outset of any colonial waterbird monitoring program. Technical instructions for counting seabirds have been established in Great Britain and Canada (Anonymous 1969; Nettleship 1976). A summary of colonial waterbird counting techniques similar to that for terrestrial birds could be written by an individual or organization or could be produced in a symposium (Ralph and Scott 1981; Verner 1986).
2. State programs to monitor colonial waterbirds should be coordinated. As nongame wildlife departments have developed, coastal surveys have become important State programs. The goals, field techniques, and common types of analysis of the various State surveys should be identified and standards adopted. The precision of counts should be improved to permit rigorous analysis. Any common goals and cooperative projects that emerge would help to define the structure of a useful database that is compatible among States.
3. Given a focus on which species to monitor and the purpose for monitoring, the operational requirements of a colonial bird monitoring program should include (a) conducting field tests of census methodology, (b) coordination of survey efforts within a region, (c) training participants, (d) promoting the program, and (e) periodically publishing results.
4. Operational requirements of a colonial waterbird data base should include (a) data entry and editing (especially checking the data for duplicate colony names and errors), (b) maintaining the data in an accessible data-storage system, (c) communicating with cooperators, (d) publishing results, and (e) performing retrievals for data users.
5. If a centralized data base is desirable, the products of the data base and sources of funding for those products should be clearly identified from the beginning.

Conclusions

The Cornell Laboratory of Ornithology discontinued the CBR in 1988 because of insufficient funds to manage the data base or to provide the guidance necessary to ensure high quality data. The CBR was the cornerstone of an ambitious landmark effort to survey and monitor colonial birds. Although new data are not being added, the extant CBR data base is available for research purposes. It is important to learn the lessons provided by the CBR because a high quality monitoring program for colonial birds is needed now as much as it was when the CBR was initiated (Parnell et al. 1988).

Acknowledgments

I thank G. S. Butcher, R. M. Erwin, and J. D. Lowe for helpful comments on the manuscript.

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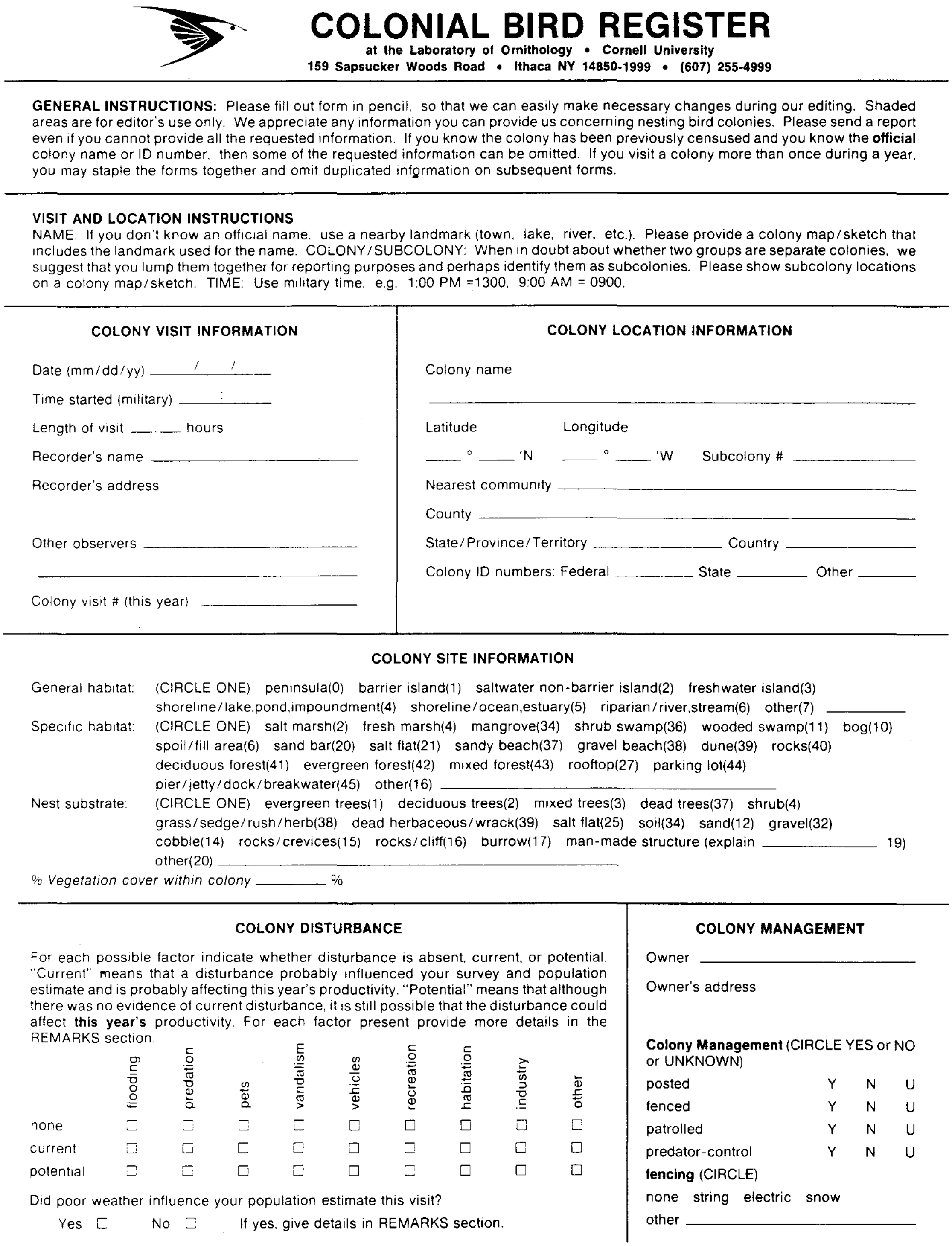
Appendix. Colonial Bird Register form.



COLONIAL BIRD REGISTER

at the Laboratory of Ornithology • Cornell University
159 Sapsucker Woods Road • Ithaca NY 14850-1999 • (607) 255-4999

GENERAL INSTRUCTIONS: Please fill out form in pencil, so that we can easily make necessary changes during our editing. Shaded areas are for editor's use only. We appreciate any information you can provide us concerning nesting bird colonies. Please send a report even if you cannot provide all the requested information. If you know the colony has been previously censused and you know the **official** colony name or ID number, then some of the requested information can be omitted. If you visit a colony more than once during a year, you may staple the forms together and omit duplicated information on subsequent forms.

VISIT AND LOCATION INSTRUCTIONS

NAME: If you don't know an official name, use a nearby landmark (town, lake, river, etc.). Please provide a colony map/sketch that includes the landmark used for the name. COLONY/SUBCOLONY: When in doubt about whether two groups are separate colonies, we suggest that you lump them together for reporting purposes and perhaps identify them as subcolonies. Please show subcolony locations on a colony map/sketch. TIME: Use military time, e.g. 1:00 PM =1300, 9:00 AM = 0900.

COLONY VISIT INFORMATION

Date (mm/dd/yy) ____/____/____
Time started (military) ____:____
Length of visit ____.____ hours
Recorder's name ____________
Recorder's address

Other observers ____________
____
Colony visit # (this year) ____________

COLONY LOCATION INFORMATION

Colony name
____
Latitude Longitude
____ ° ____ 'N ____ ° ____ 'W Subcolony # ____________
Nearest community ____________
County ____________
State/Province/Territory ____________ Country ____________
Colony ID numbers: Federal ________ State ________ Other ________

COLONY SITE INFORMATION

General habitat: (CIRCLE ONE) peninsula(0) barrier island(1) saltwater non-barrier island(2) freshwater island(3) shoreline/lake,pond,impoundment(4) shoreline/ocean,estuary(5) riparian/river,stream(6) other(7) ________

Specific habitat: (CIRCLE ONE) salt marsh(2) fresh marsh(4) mangrove(34) shrub swamp(36) wooded swamp(11) bog(10) spoil/fill area(6) sand bar(20) salt flat(21) sandy beach(37) gravel beach(38) dune(39) rocks(40) deciduous forest(41) evergreen forest(42) mixed forest(43) rooftop(27) parking lot(44) pier/jetty/dock/breakwater(45) other(16) ____________

Nest substrate: (CIRCLE ONE) evergreen trees(1) deciduous trees(2) mixed trees(3) dead trees(37) shrub(4) grass/sedge/rush/herb(38) dead herbaceous/wrack(39) salt flat(25) soil(34) sand(12) gravel(32) cobble(14) rocks/crevices(15) rocks/cliff(16) burrow(17) man-made structure (explain ________ 19) other(20) ____________

% Vegetation cover within colony ________ %

COLONY DISTURBANCE

For each possible factor indicate whether disturbance is absent, current, or potential. "Current" means that a disturbance probably influenced your survey and population estimate and is probably affecting this year's productivity. "Potential" means that although there was no evidence of current disturbance, it is still possible that the disturbance could affect **this year's** productivity. For each factor present provide more details in the REMARKS section.

	flooding	predation	pets	vandalism	vehicles	recreation	habitation	industry	other
none	☐	☐	☐	☐	☐	☐	☐	☐	☐
current	☐	☐	☐	☐	☐	☐	☐	☐	☐
potential	☐	☐	☐	☐	☐	☐	☐	☐	☐

Did poor weather influence your population estimate this visit?
Yes ☐ No ☐ If yes, give details in REMARKS section.

COLONY MANAGEMENT

Owner ____________
Owner's address

Colony Management (CIRCLE YES or NO or UNKNOWN)

posted	Y	N	U
fenced	Y	N	U
patrolled	Y	N	U
predator-control	Y	N	U

fencing (CIRCLE)
none string electric snow
other ____________

INSTRUCTIONS FOR REPRODUCTIVE INFORMATION: We are asking for two types of survey information: **(1)** what did you actually **see** (adult count, active nest count) and **(2)** what is your best estimate of the number of breeding pairs using this site this year. **Please give details of how this estimate was obtained in the REMARKS section.** Please list each species on a separate line (do not write in shaded areas). Choose codes for "counted from" and "survey technique" and write them in the boxes. Adult count (individuals) and active nest count refer to actual numbers seen on the day of the visit. Estimated # of breeding pairs refers to the total size of the colony (this may **or** may not be the same as active nests) e.g. a tern colony of 10 pairs is washed out shortly before a visit, during this visit 15 adults are seen but only 2 pairs have started to renest. Adult count (individuals) = 15, active nest count = 2, estimated # of breeding pairs = 10. For nesting stage check the appropriate box or boxes, if unknown please write "unknown" across the boxes. If you band birds, please specify adult, young, both, or none in the last column. Extra information should be put in the REMARKS section. Thanks! **COUNTED FROM:** 3-airplane, 4-helicopter, 5-boat, 6-motorized land vehicle, 7-foot (periphery of colony), 8-foot (within colony), 9-other (describe in REMARKS section) **SURVEY TECHNIQUE:** 1-total adult count, 2-total nest count, 3-photography, 4-partial adult count, 5-partial nest count, 6-quadrat sample, 7-line strip sample, 8-visual estimate, 9-best guess, 0-other (describe in REMARKS section)

REPRODUCTIVE INFORMATION

Colony name ______________________

Date ______________

Visit # ____ of ____ for this year

Sheet # ____ of ____ for this visit

species	counted from	survey tech.	% pop. surveyed	adult count individuals	active nest count	estimated # of breeding pairs	nesting stage (check appropriate boxes & circle most frequent stage)													if banding birds, specify adults, young, both, or none
							prenesting 1	pairing/terr. estab. 2	egg laying 3	incubation 4	hatching 5	downy young 6	feathered young 7	young flying/ready 8	renesting 9	loafing on colony 10	abandoned/inactive 20	postnesting 22		

REMARKS: attach additional sheets if necessary

COLONY MAP/SKETCH: (should show colony in relation to landmarks or Lat. & Long.) attach additional sheets if necessary

Descriptions of Surveys: Breeding Bird Censuses

by

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Introduction

In recent years many community ecologists have strongly emphasized the need for ecological investigations that extend over long periods, an approach also embodied in the Long-term Ecological Research Program (LTER) of the National Science Foundation (Callahan 1984). Such long-term records are perceived as providing valuable insights into a predictive capability for population and community changes over time. For example, studies of birds, particularly those conducted during the breeding season that span several consecutive years or even decades, should provide good indicators of long-term population changes and dynamics. Changes in some North American bird populations were suggested as early as 1969 by Aldrich and Robbins (1970). More recently, based on a small number of long-term census data sets, Briggs and Criswell (1979), Hall (1984 a,1984 b), and Johnston and Winings (1987) reported declines in breeding bird populations at some eastern forest sites. Nonetheless, Bohlen (1984:27) correctly cautioned that "not enough long-term censuses have been conducted to provide conclusive evidence that...species...are seriously dwindling overall."

By searching the published literature, I found 15 long-term data sets of breeding bird censuses for deciduous forest sites, mostly in the eastern United States. The sets range from 10 to 50 years, one extending back to 1927 and about half including the 1980's. The present report identifies these sites and their characteristics. Breeding bird data from the sites are discussed as being appropriate for use in monitoring avian population changes over long periods.

Sources of the Data Sets and Site Characteristics

Censuses of breeding landbirds from the United States date back to the 1914–20 surveys of the Bureau of Biological Survey (Cooke 1923), and since 1937, the National Audubon Society has sponsored annual breeding bird censuses at scattered sites and in different habitats in North America. In this paper, only data from deciduous forests in the eastern and midwestern United States have been analyzed, chiefly because of the availability of their long-term sets (at least 10 years; Table 1). I have not found long-term quantitative sets for other major ecological community-types in North America except for the reports of Hall (1984 a,1984 b) from eastern spruce forests.

Most of the data sets have been published in *Audubon Field Notes*, *American Birds*, and *The Atlantic Naturalist* (see Table 2 for additional published sources). The 15 sites were geographically widespread, ranging from south Georgia to New Hampshire and from Maryland to Illinois. Some censuses date back 50 years (Table 1; Figure).

These census sites were in ecologically similar habitats. Only mature forests (from the authors' or compilers' original descriptions) were used, and none were used in which forest succession was evident. Some sites contained a few scattered pines (and thus might not have been a true climax), but all sites were reportedly dominated by mature hardwoods of various species (e.g., oak, hickory, beech, maple) in various combinations. The estimated ages of sites and dominant tree species differed somewhat among the sites (Table 2).

The environments of some sites reportedly remained unchanged throughout the duration of the censuses, both inside and outside the site (Table 2). Other sites in Table 2 either incurred some nonsuccessional habitat changes, the magnitude of which might be questionable, or lacked convincing documentation for changes over the duration of the censuses to determine actual or possible perturbations. I contacted as many of the compilers or authors as possible, thus obtaining first-hand, crucial information on the continuity of the site within contiguous forests. For the most part, the same site and area were censused in subsequent years, and boundaries remained

Table 1. *Deciduous forest sites for long-term breeding bird censuses and years of censuses.*

Sites	First year	Last year	Number of censuses	Span (years)
Unchanged—parts of large forest tracts, remaining unisolated during census periods				
Wilkesboro, North Carolina	1954	1973	20	20
Hubbard Brook, New Hampshire	1969	1984	16	16
Dranesville, Virginia	1973	1986	14	14
Wormsloe Plantation, Georgia	1963	1973	11	11
Calhoun County, Michigan	1938	1947	10	10
Clayton, Georgia	1969	1978	10	10
Changes known or undetermined				
Trelease Woods, Illinois	1927	1976	42	50
Cabin John, Maryland	1947	1986	34	40
Rock Creek Park, District of Columbia	1948	1986	29	39
Calvert County, Maryland	1960	1986	26	27
Glover-Archbold Park, District of Columbia	1959	1986	25	28
Cleveland, Ohio	1932	1947	15	16
Greenbrook Sanctuary, New Jersey	1949	1983	11	37
Connecticut Arboretum, Connecticut	1953	1985	11	33
Licking County, Ohio	1937	1947	10	11

unchanged over the census years. At only one site was the census area changed: Rock Creek Park, where the original census area of 32.4 ha established in 1948 was reduced to 26.3 ha in 1963.

Census Methods

Although some censustakers and annual compilers might have changed at a given site over the years, methods for censusing and tabulating the breeding bird populations did not; census methods reportedly followed the widely used spot-mapping–singing male–territory mapping technique. This technique, as described by Williams (1936) and Stewart and Aldrich (1949), is based on the spacing of (most) forest breeding birds into territories identified chiefly by the locations of males, their conspicuous vocalizations, and behavior patterns. By mapping locations of all (singing) males (and pairs) in a census area on different days during the breeding season, one can identify territories reasonably accurately. By assuming that each territory contains or will contain a pair of the species, the number of occupied territories can be translated into the number of pairs of each species breeding on a given site.

The Data Sets

For the purpose of a comparative analysis, the number of breeding pairs at each site as reported by the compiler or author has been standardized to the number of pairs per 100 acres. For each year the total breeding pairs at a site can be subdivided into two components: neotropical migrant species and short-distance migrant–resident species. Thus, for each census-year at a given site, three numbers are available (all in breeding pairs per 100 acres): total birds, neotropical migrants, and short-distance migrants or residents.

Some of the data sets are clearly periodic, that is, censuses are equally spaced over the years (Table 1). For the sets in Table 1 and the Figure, periodic ones are those in which censuses were reported for every year over the time span; other sets had gaps in the years censused (i.e., aperiodic).

Potential Limitations of the Data Sets

Despite the perceived value of these long-term data sets, the following potential limitations for estimating population trends are recognized (see also discussions by various authors in Ralph and Scott 1981):

- the aperiodicity of some of the data sets;
- variation in census effort (man-hours expended);
- inadequate vegetation–site description at the inception of the first census; thus, the true ecological age of the site might be unknown;
- biased estimates, such as overestimation of population density by assuming that a singing male on territory truly represents a breeding pair, or underestimating population density if some males were not singing on a territory and hence were not counted;

Table 2. *Deciduous forest breeding bird census sites, sizes, and brief descriptions.*

Site	Size (ha)	Description[a]
Wilkesboro, North Carolina[b]	16.2	Hardwoods with some white pine. No major habitat changes inside or outside
Hubbard Brook, New Hampshire[c]	10	Unfragmented temperate deciduous forest
Dranesville, Virginia[b]	11	Uniform hardwoods; part of 140-ha tract
Wormsloe Plantation, Georgia[b]	10	Oak–pine forest; part of 130-ha tract
Calhoun County, Michigan[b]	5	Oak–hickory forest; part of 40-ha woodlot
Clayton, Georgia[b]	6.1	Montane hardwood forest; part of extensive national forest
Trelease Woods, Illinois[d]	24	Mature mixed hardwoods; field edge extant since 1927
Cabin John, Maryland[b]	7.6	100-year-old riverine forest; road constructed nearby in 1958[h]
Rock Creek Park, District of Columbia[b]	32.4[g]	80-year-old hardwood forest with scattered pine; road construction along one edge
Calvert County, Maryland[b]	11.3	Mixed hardwoods, upland; some logging inside and outside tract in 1976
Glover-Archbold Park, District of Columbia[b]	14.2	Mixed hardwoods, upland; unknown habitat changes outside
Cleveland, Ohio[b]	26.3	Climax beech–maple with some hemlock; unknown changes outside
Greenbrook Sanctuary, New Jersey[e]	66.8	Mixed northern hardwoods; "most neighboring woodlands have remained intact"
Connecticut Arboretum, Connecticut[f]	23	Hemlock hardwoods; always isolated
Licking County, Ohio[b]	14.2	Oak–hickory forest, upland; some clearing on one edge in 1945

[a] Extracted from compilers' or authors' account.
[b] Data from *Audubon Field Notes* and *American Birds*.
[c] Holmes et al. 1986.
[d] Kendeigh 1982.
[e] J. Serrao 1985 and personal communication.
[f] Butcher et al. 1981.
[g] Reduced to 26.3 ha in 1963.
[h] Criswell and Gauthey 1980.

- failure to discover any perturbations (physical or biological) occurring inside or immediately contiguous to the site; and
- variation in observer competency.

All the sets in Table 1 are probably more or less equally affected by these possible limitations, so the sets are considered here to be comparable.

I am aware that some relevant information about the sites might be unavailable or indeterminate. For example,

- How and why were the sites originally selected? For easy transportation distance? Historically, were these sites simply "good birding spots?"
- Are these sites truly representative of eastern deciduous forests and their breeding bird populations, both geographically and temporally?
- Are population data from the sites comparable because of the known differences in site-sizes, geography, and plant-species composition?

Analysis of the Data Sets

In another paper in these workshop proceedings, S. R. Taub presents a procedure for examining these data sets to discover whether they reveal any temporal trends.

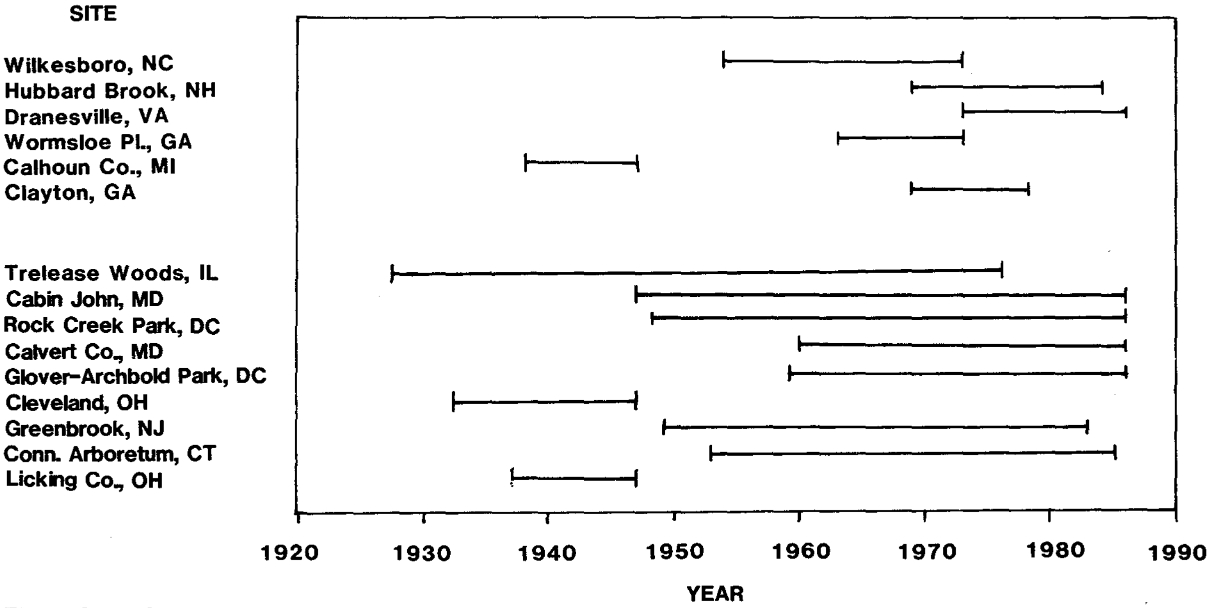

Figure. Span of years for breeding bird censuses at deciduous forest sites.

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Migration Banding Data: a Source of Information on Bird Population Trends?

by

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Introduction

Interest by North American banders in the capture and banding of birds during migration greatly increased following World War II when mist nets manufactured in Japan became available (Low 1957). Mist nets allowed nonselective capture of a wide variety of bird species, thus providing a more accurate sample of passerines than other capture techniques. The first serious attempt to capture and band large numbers of passerine migrants at a known concentration point occurred at Cape May, New Jersey, in 1951–53, when approximately 18 mist nets were operated for one weekend each September (Baird et al. 1958). The success of this operation led to an organized effort to band migrants at concentration points along the Atlantic Coast. Operation Recovery, as the project became known, was initiated in 1955, with seven netting stations at coastal locations in Maryland, Massachusetts, New Jersey, Rhode Island, and Virginia in operation during parts of August and September (Baird et al. 1958). At the outset of the project, the coordinators envisioned that the movements of migrants could be tracked southward. The paucity of recoveries prompted the expansion of objectives to include study of the effects of weather on migration, the relation between visual counts of migrants and mist net captures, and the use of bird weights as an aid in interpreting migration data (Baird et al. 1958).

Banders were originally requested to concentrate banding activities within a 2-week period, during late August in the Maritime Provinces to late September south of Maryland. As interest in the project and the number of experienced banders increased, many stations expanded coverage and banded throughout the fall migration period, and several stations began to operate during spring migration. In addition, stations were established at a number of inland sites. The number of banding stations participating in Operation Recovery varied from year to year; by 1960, approximately 50 stations were in operation during the fall migration, capturing and banding more than 60,000 birds (Bird Banding Laboratory 1961).

The U.S. Fish and Wildlife Service (FWS) sponsored Operation Recovery, entering the data into computer files and providing analytical support, through 1969. Thereafter, the Eastern Bird Banding Association (EBBA) published summaries for stations that continued to operate, first in *EBBA News*, later in *North American Bird Bander* (NABB). In recent years about 40 banding stations in the eastern United States have submitted annual summaries of fall banding activities for publication in the NABB *Atlantic Flyway Reviews*. No comparable summaries of migration banding activities elsewhere in North America are currently being published; however, relatively few banders in other regions operate stations regularly during migration (S. M. Russell, personal communication).

Since the start of Operation Recovery, banding effort has varied widely among the participating stations, ranging from a few mist nets operated occasionally in a bander's backyard to 50 or more nets run daily from dawn until dusk at established bird observatories. In recent years, approximately 15 stations in the eastern United States operate on a regular basis during fall migration; fewer stations operate during spring migration. Banders are strongly encouraged to record the number of nets and hours in operation for each day of banding (Baird et al. 1958; Robbins 1968). All unmarked birds captured are identified and banded with FWS aluminum bands. Whenever possible, the age and sex are determined, using characters such as plumage, eye or bill color, wing chord length, and degree of skull pneumatization. Banders are required to submit schedules to either the FWS Bird Banding Laboratory (for birds banded in the United States) or Canadian Wildlife Service (for birds banded in Canada), reporting species, age, sex, and date and location of capture for each band used. All bandings of nongame bird species since 1954 are stored in computer files at the Bird Banding Laboratory in the form of monthly summaries of all birds of the same species, age, and sex, banded under the same permit number, within the same 10-min block of latitude and longitude.

Concerns About the Use of Migration Data for Trend Estimation

The measurement of trends in numbers of different passerines has long been recognized as a possible use of data from migration stations (Bergstrom and Drury 1956). Most banders, in summarizing a season's results, compare captures to those of previous years, indicating they believe that mist net samples provide an index of actual population levels for species. However, few banders have attempted to statistically analyze long-term changes in numbers of migrating birds (but see Hussell 1981; Jones 1986; Stewart 1987).

Migration data receive little use for estimating passerine population trends for several reasons. Although many banders now own microcomputers and routinely enter data they collect, few possess the statistical knowledge and software required for data analysis. Even among those knowledgeable in statistics, two major concerns exist regarding the use of migration data for monitoring population change. First, because populations of migrants cannot be associated with specific breeding or wintering areas, it is not known if the same source population is being sampled each year by a banding station. Second, factors other than population change contribute to variability in annual counts of migrating birds. Regional and local changes in habitat could influence use of a stopover site by migrants. In a study conducted in riparian habitats in the lower Colorado River valley, Anderson et al. (1983) found that fall avian communities were more closely associated with vegetation parameters than were breeding season avian communities. However, habitat use patterns for most passerine species at migration stopover points have not been documented (but see Parnell 1969; Yahner 1983; Hutto 1985; Martin and Karr 1986). Very few migrants are recaptured at the banding station of initial capture in subsequent years, suggesting that birds do not exhibit fidelity to stopover sites. Further research is required to determine if migrating passerines select stopover sites in which they are captured or if presence at a site is irrespective of its habitat attributes.

Weather greatly affects the migration of birds (Richardson 1978). Regional patterns can influence the timing and volume of flights and the migration routes and stopover points used; local conditions can influence length of stay by migrants at stopover sites (and hence their capture probabilities), daily operation of banding stations, and the effectiveness of mist nets.

Bird species vary both in their seasonal patterns of migration (timing and distribution, Hall 1981) and in their diurnal activity patterns at stopover sites (Atwood et al. 1988). Thus, variation in banding effort among years, both in total effort and in the distribution of effort throughout the day and season, can cause variability in seasonal captures of birds that is not related to population change.

On the other hand, species identification of birds sampled with mist nets is generally not subject to the observer biases inherent in surveys based on visual or aural counts of birds. However, the accurate assessment of bird age and sex requires a level of expertise that varies among banders. In addition, the reliability of the characters used in age and sex assessment varies with time of year and among bird species. Thus, these data should be used with caution.

Deriving an Index to Seasonal Totals

In using migration data to estimate long-term changes in bird populations, the first task is to define a dependent variable, an index that characterizes the number of individuals of a species that pass through a banding site in a season. An obvious index is simply the total captures of the species for the season. This index is probably only reasonable if weather and effort at a site are consistent among years. Hussell (1981) developed multiple regression techniques that attempt to correct migration indices for the effects of weather factors; however, these techniques are complex and difficult to apply.

Seasonal captures can also be adjusted statistically to account for variation in effort among years. A commonly used adjustment for effort is to weight total captures of a species by total effort (expressed as net-hours) during the season. If the distribution of effort throughout the season varies among years, a more refined adjustment for each species may be desired. Total counts (captures) of a species weighted by effort expended during the period in which the species is migrating through a site (or during the period in which 95% of the individuals of the species are counted or captured) has been used as a seasonal index of migrating raptors in analyses of population trends (Titus and Mosher 1982). Another approach is to statistically standardize the number of days of operation among years by estimating captures for a species for days when the banding station was closed. Hussell and Risley (1978) replaced missing data with the long-term average of counts for a species for that date, then summed daily counts for the species over the entire season. We (D. K. Dawson and J. R. Sauer, unpublished) have proposed a technique that involves breaking the migration period into intervals (of 5 days or longer), calculating mean daily captures per net-hours for a species within each interval, using the mean as an estimate of captures for missing days within an interval, and summing these weighted daily captures over the banding season (Dawson and Sauer, unpublished). This adjustment may be particularly appropriate for species for which between-interval variation in daily captures per unit effort is significantly greater than within-interval variation. Variability in effort among days can be accounted for by including captures only from the hours during which the station is operated regularly or by weighting effort during different periods of the day (Ralph 1976). Although it is possible to adjust captures to account for variability in effort, the reliability of the indices is reduced as the number of days increases for which estimates are substituted for actual captures. Thus, if monitoring population changes is to be one of the goals of migration banding, banders should strive to have effort as consistent as possible among days and among years.

Research Plans

A study has been initiated by the FWS to evaluate the potential for estimating bird population trends from migration banding data. We propose to adapt the route-regression methodology developed for analysis of population trends from Breeding Bird Survey data (Geissler and Noon 1981; Robbins et al. 1986) to estimate trends for banding stations in the Atlantic Flyway (stations operated on a regular basis during fall migrations over the past 10 years), then derive composite estimates for the region based on weighted averages of the estimates from individual stations. Combined estimates of trends may more accurately reflect actual population trends than do trends from any one station. The validity of the trends will be assessed by comparisons with trends for the species estimated from Breeding Bird Survey (BBS) data. We also plan some analyses of patterns of year-to-year change and long-term trends within species among banding stations and among species within stations that will further enable us to assess whether migration banding data are reflecting population changes or simply reflecting local phenomena.

Because of the efforts of the many dedicated banders and the resources of the Bird Banding Laboratory required to process and store all the data they collect, the large set of data collected at migration banding stations should be evaluated as to its potential for monitoring bird populations. Migration banding data could be useful in corroborating trends estimated for species using data from the Breeding Bird Survey or Christmas Bird Count and in estimating trends for species that are not well sampled by these monitoring techniques. Migration banding data offer two additional potential uses: (1) to monitor trends of adults returning from wintering grounds (using spring migration data), and (2) to monitor trends in the number of adults and young surviving the breeding season (using data collected during fall for species for which age class can be accurately assessed). For species with declining populations, examination of trends from two seasons and for the two age classes might suggest if declines are associated with the breeding grounds or with the wintering grounds.

Acknowledgments

S. Droege, J. M. Hagan, G. A. Hall, and J. R. Sauer provided helpful comments on earlier drafts of the manuscript.

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Sources of Migrant Hawk Counts For Monitoring Raptor Populations

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Introduction

Many species of Falconiformes and Strigiformes become concentrated during spring and fall migration, at which time they can be counted much more readily than when they are dispersed during the breeding season. Depending on species and season, migrant raptors can be seen in numbers of tens to thousands per day at certain geomorphological sites and during certain meteorological conditions (Haugh 1986). Since the 1960's, yearly counts of migrants have been used to infer changes in the population sizes of raptors (e.g., Spofford 1969; Hackman and Henny 1971; Robbins 1975; U.S. Department of the Interior 1976). With the yearly accumulation of counts, including counts from new sites since the late 1970's and early 1980's, biologists recently have undertaken more detailed analyses of counts with the goal of describing population trends (Dekker 1984; Hussell 1985; Mueller et al. 1988; Ward et al. 1988). In this paper we briefly relate the history of standardized counts of migrant raptors (hawk counts), describe counting and data recording procedures, and discuss the analysis and interpretation of data from six sites in North America (Titus et al. 1989, 1990).

History of Hawk Counts

Since the late 1800's, American ornithologists have described concentrations of migrating raptors (Stone 1887; Trowbridge 1895; Broun 1935; Allen and Peterson 1936). By the early 1970's the number of sites at which migrant raptors were observed had exceeded 100, and biologists and amateurs had begun to count raptors, record data, and study migration (Haugh and Cade 1966; Hofslund 1966; Mueller and Berger 1967; Ward and Berry 1972; Evans 1975). Interest in raptor migration grew to such an extent that a planning committee organized the 1974 North American Hawk Migration Conference (April 1974, Syracuse, New York). Harwood (1975a) wrote that it was organized, in part, to resolve problems associated with using the results of hawkwatching. He cited as impediments to further study of raptor migration the inconsistencies in data recording methods and the inability to readily obtain reports from a number of sites or from a number of years. The conference resulted in the formation of the Hawk Migration Association of North America (HMANA) to enhance communication among observers and to act as a repository for data (Harwood 1975b). The *Newsletter of HMANA* was initiated to disseminate count summaries and articles. Also, a committee developed brief instructions and a form on which observations and counts could be recorded.

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Observers were encouraged to complete a form for each day during which counts were made at a site, and then send the form to a regional editor who would check the records for clarity and completeness before sending them to the central repository. The HMANA stored the forms and made them available for study.

Robbins (1975) presented the only paper at the 1974 North American Hawk Migration Conference that addressed using hawk counts for monitoring populations. He described the early history of hawkwatching, and referred to a program of the early 1950's sponsored by the Bureau of Sport Fisheries and Wildlife to accumulate counts of migrants as a population index. Robbins (1975) cited the analysis of hawk counts that he and J. L. Ruos conducted for consideration in a migratory bird treaty with Mexico (Anonymous 1971). Robbins (1975) emphasized the necessity of standardization and consistency of observation and reporting procedures if hawk counts were to be used for monitoring population changes.

The HMANA first distributed forms in the fall of 1974, and in 1975 volunteers returned forms from 85 count sites. From the outset HMANA recognized the usefulness of maintaining a computerized data bank. The U.S. Fish and Wildlife Service (Service) collaborated with HMANA to evaluate the potential for transferring data from HMANA forms to a computer. The Service was hopeful that a hawk count data bank could be used in its efforts to monitor migratory bird population trends. Evaluations using forms from 1974 through 1978 revealed that there were still many inconsistencies in observation methods, data recording (e.g., use of different measurement units), and editing, and that there were many errors and incomplete data. Based on the evaluation and consultation with HMANA members and research and management biologists, more detailed instructions for recording data and a revised form (Figure) were adopted (Fuller and Robbins 1979). In 1979 the Service's Office of Migratory Bird Management began collaborating with staff at six count sites to obtain more complete and consistent data. Titus et al. (1990) began evaluating the data from the six sites which include: fall counts from 1976 to 1987 at Cape May, New Jersey (Allen and Peterson 1936); spring counts from 1979 to 1987 at Derby Hill, New York (Haugh and Cade 1966); fall counts from 1972 to 1987 at Hawk Mountain, Pennsylvania (Broun 1935), and 1972 to 1987 at Hawk Ridge, Minnesota (Hofslund 1966); and spring counts from 1979 to 1987 at Sandy Hook, New Jersey (Clark 1978), and 1980 to 1987 at Whitefish Point, Michigan (Devereux et al. 1985).

Records from these six sites are more complete and contain fewer errors than records from sites contributing to HMANA in the 1970's. There are some missing data in the records from the six sites (Titus et al. 1989) and, in some cases (e.g., weather data), missing data can preclude or confound some analyses (Hussell 1985). However, the records from these sites have been useful for exploring methods for detecting trends in counts of migrant raptors (Titus et al. 1990). The Office of Migratory Bird Management continues to collaborate with contributors from the six sites to accumulate hawk count data (J. Trapp, personal communication). Data from 1980 through the present at all sites except Hawk Mountain have been summarized at Patuxent Wildlife Research Center (Titus et al. 1989, 1990). The long-term (1934 to present) data from the Hawk Mountain Sanctuary data bank are being analyzed in detail by Sanctuary staff. The six data sets vary in size, with sites such as Cape May and Hawk Mountain averaging slightly more than 100 days of observation per year, while counts at Whitefish Point have been conducted about 60 days per year.

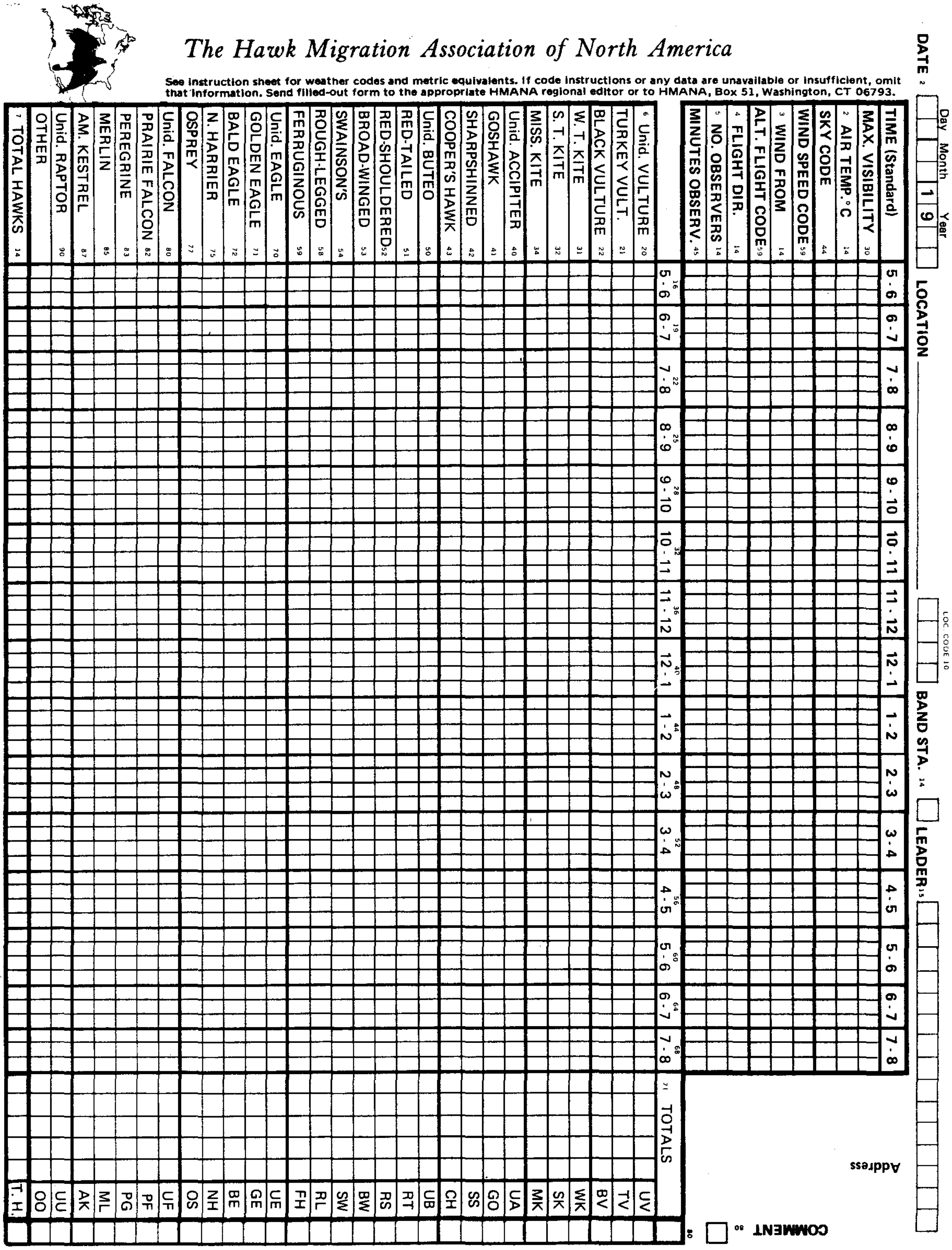
Currently HMANA is evaluating its criteria for accepting data forms and for maintaining a computerized data bank (M. Harwood, personal communication). Some data are available for study from HMANA (c/o Myriam Moore, Secretary, P.O. Box 3482, Lynchburg, Virginia 24503), and the association can provide addresses of individuals working at each of the sites.

Hawk Counts and Data Recording

Hawk counts have been conducted at specific sites simply because observers are often rewarded with larger numbers of raptors than can be seen in the adjacent countryside. Descriptions of 16 sites and examples of species counts are given by Harwood (1975c:5–28). Also, counts of migrants are collected at some sites by persons who are trapping and banding birds (Mueller and Berger 1967; Ward and Berry 1972; Evans 1975). The data analyzed by Titus et al. (1990) were gathered by biologists who only counted hawks.

Haugh (1986) summarized how topographical features such as mountain ridges and shorelines, the air currents (e.g., updrafts) associated with these features, meteorological conditions, and seasonal timing are believed to influence concentrations of migrants. The behavior of migrating raptors has been studied recently by Kerlinger (1985), Kerlinger and Gauthreaux (1985), and Kerlinger et al. (1985). Information about migrant behavior and the influence of weather, seasonality, and daily rhythms on flights is often used by hawkwatchers to plan counts for those times when large flights are likely. However, we do not know of any statistically based sampling designs in the scheduling of counts. Titus et al. (1989) presented examples of how sampling designs could be applied to hawk counts.

We are not aware of routines for sampling portions of the sky, or for sampling intervals during the time an



The Hawk Migration Association of North America

See instruction sheet for weather codes and metric equivalents. If code instructions or any data are unavailable or insufficient, omit that information. Send filled-out form to the appropriate HMANA regional editor or to HMANA, Box 51, Washington, CT 06793.

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7 TOTAL HAWKS 14																	T.H.

COMMENT 80 ☐ 80

Figure. Form for collection of hawk migration data. This form was created by the Hawk Migration Association of North America and the U.S. Fish and Wildlife Service to establish a computerized data bank on hawk migration.

observer is on the watch site. There are some general guidelines for hawkwatching and counting (e.g., Dunne et al. 1984; Heintzelman 1986), and it is known that factors such as fatigue (Sattler and Bart 1984), multiple observers (Hussell 1985), and location of observer (Kochenberger and Dunne 1985) can affect counts. However, we have not found instructions for dealing with these factors when conducting counts for the purpose of monitoring.

The HMANA instructions relate to the types of data to be gathered and describe how to complete the standard form to be used at all sites contributing to the HMANA data bank. The instructions stress completeness and neatness when filling in the form (Figure). There is a column to indicate that a comment has been made elsewhere in reference to information on the form, and observers are encouraged to supply additional information. We stress the importance of completing the section containing observation conditions because it includes factors that can contribute to variability among counts. There is space for an estimate of maximum visibility and for recording temperature (a metric conversion table is included). A "sky code" is provided for describing the percentage of cloud cover or type of precipitation, along with a code for wind speed and wind direction. There is a code for estimating the altitude of flight. Finally, there is space to record the numbers of observers each hour, and the total minutes during which counts were made each hour.

Considerations for Using Hawk Counts

The observation and recording of hawk counts causes some variability in data from within and among sites. Fuller and Robbins (1979) and Titus et al. (1989) found illegible data entries and missing data due to periods of no observation, as well as missing entries during observation periods. For example, 3–5% of the weather data were not gathered or were omitted on the forms from the six sites (Titus et al. 1989). Weather data can be important in accounting for variability in hawk counts (Hussell 1985). In addition to observer recording errors, observer fatigue (Sattler and Bart 1984), and number of observers (Hussell 1985), variability in counts is confounded by the species of raptor (Sattler and Bart 1984), the altitude of the passing migrants (Sattler and Bart 1984; Kerlinger 1985; Smith 1985), and the number of birds in a flight (Kochenberger and Dunne 1985).

Yearly counts vary widely among species and sites. For example, the mean count of golden eagles (*Aquila chrysaetos*) was 9.1/year ($n = 8$) at Whitefish Point, and the mean count of sharp-shinned hawks (*Accipiter striatus*) was 39,632/year ($n = 12$) at Cape May (Titus et al. 1990). Titus et al. (1989) found a coefficient of variation (C.V.) of about 40% for the counts of all species from six sites. However, for many individual species, the C.V. stabilized around 25% after counts from 10 years or more were accumulated for a site. The extent to which data about sources of variability can be useful for interpreting counts is evidenced in multiple regression analyses by Hussell (1985). He found that 69% of the variability in counts (birds per hour) of sharp-shinned hawks, and 52% of the variability for broad-winged hawk (*Buteo platypterus*) counts, was explained by independent variables (e.g., weather, date, year). The careful recording of data relevant to sources of variability is important for using hawk count data to monitor populations.

Suggestions for Future Work

Study of several other aspects of raptor migration would be useful for population monitoring (Fuller 1979; Haugh 1986). There is little information about the origin and destination of migrants. Banding data provide only very general information about the long-distance movements of migrants (Clark 1985; Evans and Rosenfield 1985; Yates et al. 1988). Thus, a significant change in a migration count cannot be associated with clearly defined breeding or wintering areas. Furthermore, the extent to which migrants use the same migration routes from year to year has not been quantified. Thus a change in count from one area might reflect a shift in flight path or a fluctuation in population size. Additional study is needed to determine the value of pooling data from several sites (e.g., Titus et al. 1990), and to determine if data from spring counts are less variable than those from fall counts. Analytical considerations include topics such as the implications of autocorrelation among yearly counts, the use of standardization (e.g., hawks per hour of observation), and appropriate statistical tests. Counts of migrating raptors have been used in migratory bird management (e.g., U.S. Department of the Interior 1976, 1983, 1987) and have the potential to provide even more useful data as we learn more about raptor migration.

Acknowledgments

We thank S. S. Klugman for help in preparing this manuscript, and W. S. Seegar, F. P. Ward, and the U.S. Fish and Wildlife Service, Office of Migratory Bird Management, for support of our studies of migration. S. Droege and J. R. Sauer provided reviews.

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The Common Birds Census in the United Kingdom

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Introduction

The Common Birds Census (CBC) in Britain is based on the use of a territory mapping method developed in Sweden by Enemar (1959), subsequently modified by Williamson and Homes (1964) for use in Britain. Spot-mapping censuses conducted on plots spread throughout Britain are used to provide an annual index of population trends in the species covered. The scheme was started by the British Trust for Ornithology (BTO) in 1962 at the request of the United Kingdom's statutory Nature Conservancy (now the Nature Conservancy Council [NCC]), with the aim of monitoring bird population numbers in Britain. The immediate stimulus for the initiation of the scheme was concern over the growing use of agricultural chemicals in Britain, where large-scale mortalities associated with the use of persistent organochlorine chemicals were frequently noted throughout the 1950's (Cramp et al. 1962). The concept of the CBC was to provide a bird population monitoring scheme as a bio-indicator, providing an early warning of future environmental problems. In this way the scheme might allow the NCC or other agencies to start research to find solutions before the problem(s) became severe. A second factor of concern in farmland was the accelerating destruction of hedgerows in Britain, which in the early 1960's were being removed for field enlargement at a rate of up to 1.8 m/ha (about 1.5% of the total) each year (O'Connor and Shrubb 1986).

In 1964 the CBC was extended to encompass woodland bird populations. In this habitat the census methods differ in detail from those appropriate to farmland (Williamson 1964). Many of the species on farmland are generalists of woodland origin and appear in both indexes, but a number of species are largely confined to the woodland habitat and are, therefore, covered only by the woodland CBC index. Additionally, several scarce species occurring in low numbers both in farmland and in woodland have been monitored through a Scarce Species Index. This index is obtained by merging the available data from the farmland and woodland plots with data from a number of special sites that are neither farmland nor woodland but which for various reasons have had CBC census work undertaken on them. Such sites include, for example, some bird observatories and nature reserves. This index is susceptible to changes in the representation of the different habitats within the sample, but does provide some crude measure of large-scale population trend (Batten 1971).

A linear analogue of the CBC, the Waterways Bird Survey (WBS), was started in 1964 as a means of monitoring riparian bird populations along natural and man-made watercourses. The linear nature of the census plots in this scheme greatly simplifies the problems to be addressed (review in Taylor 1983).

Design of the Survey

Census Plot Sample

As a national monitoring scheme, the CBC should have plots distributed across the country in a manner representative of farmland and woodland habitats. In practice, the scheme is limited by the distribution of the BTO membership, which is concentrated in the southeast of England. Historically, the CBC has had about 300–350 plots censused in any given year, with this total partly inflated by a significant number of the special plots outside the main farmland and woodland habitats. Up to a quarter of the observers leave the scheme each year and are replaced by new observers, and since data from a plot must be paired across years, not all plots can be used for a given year's index. As a working target for usable results, about 100 farmland and 100 woodland plots are regarded as satisfactory. Current practice requires that a species be recorded on a minimum of 30 plots each year if an index value is to be calculated for it, and a national sample of 100 therefore implies that only species present on 30% or more of the plots can be covered by a CBC index. In recent years, there has been some difficulty in meeting this criterion for all species, and some of the published indexes have fallen below this limit. In 1986–87, the most recent period for which data were available at the time of writing, some 78 farmland and 80 woodland plots contributed to the index calculations, and 9 of the 49 population changes reported were based on fewer than 30 plots, the lowest being based on 17 plots (Marchant and Whittington 1988). While there is no definitive statistical basis for the cutoff at 30 plots, smaller samples are increasingly vulnerable to the random walk effect described by Geissler and Noon (1981). The statistical basis for the historic success of the CBC thus seems to be in danger of being eroded by the dwindling sample size.

CBC plots are self-selected by the observers, and their geographical distribution is therefore not stratified, but the CBC staff make some effort to ensure that some plots are censused in most parts of the country each year. In practice, this has been moderately successful in maintaining regional coverage. Fuller et al. (1985) found no evidence of any geographical shifts in the distribution of farmland CBC plots from 1965 to 1981. They also reported an analysis of the extent to which these plots mirrored land class and farming practices in Britain. They found that the CBC plots were reasonably representative of agriculture in lowland England, specifically south of a line about latitude 54°30'N and east of longitude 3°30'W. North and west of these lines, however, certain land classes and farm types were underrepresented. There has been no serious attempt to evaluate how representative of woodland the historic CBC plots have been.

Fieldwork at a Census Plot

The CBC requires that observers visit a defined census plot 8–12 times through the breeding season. The observers agree on the plot boundary with BTO staff before starting. Plots on farmland must exceed 40 ha (100 acres) to be minimally acceptable, with 60 ha (150 acres) preferred, but woodland plots can be as small as 10 ha (25 acres). (In 1986–87 mean areas of farmland and woodland plots were 73.1 ha and 20.7 ha, respectively.) The BTO provides the observers with copies of a large-scale (1:2,500) map of the plot. On these maps, observers record the locations of all birds seen or heard, including all information relevant to territorial or breeding behavior. The registrations are plotted using standard symbols to indicate the different types of evidence obtained, such as song and alarm calls; behavior such as fighting, carrying food, or movements within the plot; the location of nests found (although no specific search for nests is required); the sex of the birds seen; and family parties seen. Considerable emphasis is put on the recording of contemporaneous registrations of different birds because such registrations guarantee that two territories are involved.

Standard coverage of a CBC plot is 10 complete mapping visits during a breeding season that, in southern Britain, runs from mid-March to late June. This number is sufficient to detect a large proportion of territories on the census plot under British conditions, while a larger number yields rapidly diminishing returns (Svensson 1979; O'Connor and Marchant 1981). In the midlands the field season may be later, with first visits undertaken in early April, and in northern Scotland visits may extend into early July. Visits are spaced evenly throughout the season, insofar as weather and the availability of the observer's time permit, with weekly visits regarded as ideal. Partial visits are allowed in three circumstances: (1) where a full visit has to be abandoned due to heavy rain, (2) to obtain special types of registration (e.g., of crepuscular or nocturnal species), and (3) where a large plot of special interest to the BTO has been designated for a group census in which each group member censuses only part of the plot.

Morning visits are the norm, but evening visits may be especially valuable in the early part of the season when certain species (e.g., song thrush, *Turdus philomelos*), sing to greatest extent late in the day. Observers are instructed not to census around dawn, when bird detectability may change very rapidly, nor during the afternoon lull in activity. Field time is recorded and used in conjunction with the number and type of visits to provide a rough check on consistency of effort across years, because field time is a significant correlate of census efficiency (O'Connor and Marchant 1981; O'Connor 1981c). On farmland, observers are advised to spend about 1 h per 20 ha of plot and are expressly asked to go into all major habitat patches (chiefly hedgerows and small woodlands) and along the perimeter of the plot. They are allowed to spend more time in areas of high bird density than in areas of low density. In woodland, a plot of 20 ha would require 3–4 h of fieldwork, with the observers free to select their routes within the plot but asked to come within 25 m of every point therein. Two habitat-related differences are of note. First, farmland generates relatively more sight registrations and woodland relatively more sound registrations. Second, woodland plots often need prior gridding for accurate mapping, while the matrix of fields and hedges on farmland often provides a natural reference net. The CBC Instructions also suggest varying the start point for different visits, to minimize potential for absolute bias, though always with emphasis on across-year consistency.

Not all species lend themselves well to territorial mapping, and the census is therefore supplemented for such species by nest counts where nesting is conspicuous (e.g., grey heron, *Ardea cinerea*) or colonial (e.g., sand martin, *Riparia riparia*). Other species (e.g., woodpigeon, *Columba palumbus*, swallow, *Hirundo rustica*, and starling, *Sturnus vulgaris*) are more easily censused by nest counts than by territory mapping, but at a cost in time unacceptable to some observers. For these the population estimate is taken from a comprehensive nest count where possible and a combined nest and territory total otherwise.

Since registrations have later to be assigned to individual clusters, the problem of mapping at the edge of the census plot can be significant (Marchant 1981; Verner 1985). An arbitrary cutoff is unsatisfactory, for observers may then tend to record registrations just outside the boundary as being inside it. This applies also where the plot is embedded in a larger area of the same habitat. On farmland, observers are instructed not to use imaginary boundaries running, for example, through the middle of a field, but to use physical, identifiable boundaries. At the same time they should not use especially rich areas, such as a diverse shelter-belt, for this purpose. With these guidelines they then record all registrations near the boundary, but map them in their true locations, whether inside or beyond the boundary. This then permits the analysts to subsequently assign these boundary territories in some appropriate manner, currently by including them if more than one half of the registrations lie inside the plot boundary and excluding them otherwise. Even with this rule, however, a small residual overestimate of density is possible, because observer coverage is greater within the plot boundary (Marchant 1981).

Additional Field Data

Observers are asked to submit plot habitat data to the BTO. A full habitat map of the plot is requested for the first year of a plot census, but in subsequent years only habitat changes and year-specific information (such as cropping plans for farmland) are required. In theory each observer also completes a habitat questionnaire to accompany such maps, but in practice these returns are incomplete, to the point of limiting some analyses otherwise feasible.

Farmland habitat details describe the landscape elements of the plot – the location of hedgerows and small woodlots, their species composition, the size and shape (a function of management) of the hedges, and the location, species, and size of standard (i.e., well-grown) trees in the hedges. Watercourses and small ponds are also indicated, as is the basic topography of the plot. Annual cropping plans show the crops used in each field, sometimes with quite detailed information on their management. Landscape elements are readily recognized by observers, and information is often very well recorded in the farmland returns. For woodland plots, however, the instructions call for structure and management information that is much harder to relate to without ecological training, and data received are rather poor. In practice these data have been discarded by researchers, and most of the studies of woodland bird habitat requirements have been based on data gathered expressly for the purpose by BTO staff and others.

Analysis of Census Data

On completion of the fieldwork each season, the information from the visit maps is collated by the observer onto species maps, with the registrations typically falling into (presumed territory) clusters. Significant difficulties arise over the interpretation of such data (Svensson 1974; Best 1975; Fuller and Marchant 1985). The CBC minimizes these problems by using trained staff and standard rules (contained in the CBC manual *Guiding Principles* and similar to those adopted by the International Bird Census Committee [Anonymous 1969]) to produce definitive cluster maps. The observers provide preliminary analyses that often assist the professional analysts. In interpreting the clusters as territories, emphasis is placed on using singing males and on contemporaneous registrations, with the intention of maximizing the agreement between the total number of clusters and the total number of territories on the plot.

Agreement between the location and number of clusters and the location and numbers of territories on the census plot is affected by the efficiency of the field worker and by bird behavior. Within a given type of habitat, the behavior of each species is likely to be relatively constant but to differ between species. Hence, a given observer detects the different species at different rates. However, individual observers may differ in their personal census efficiency, so that they would obtain different results were they to census the same census plot. In practice it is impossible to normalize these efficiencies to a common value for each species. The CBC therefore describes population levels through the construction of a CBC *Index* (Bailey 1967) whose calculation effectively eliminates the observer census efficiencies. This is achieved by pairing the plots across years and computing a pooled estimate of the percentage change between the 2 years. These year-on-year relative changes are then chained together on a base year value (for most species arbitrarily set to 100 in 1966) to generate an index proportional (but by an unknown factor) over time to the true density of the species. However, this index requires that each observer remain constant in efficiency, even though the level of this efficiency is actually unknown and may differ from one observer to another.

Completion of the analysis of each year's returns typically requires the work of three to four analysts from August through April. An interim mimeographed report based on the early returns is circulated to participants midway through this period, and a short annual report is published in the Trust's newsletter, *BTO News*.

Constraints on the Analysis of the Survey

Limitations on the CBC scheme are of two types, those imposed by assumptions intrinsic to the design of the survey and those imposed by external constraints on its staffing. Five major assumptions are made within the CBC design: (1) census efficiency may differ between observers without biasing the index; (2) individual observers are constant in census efficiency over time; (3) the average efficiency of the pool of observers does not drift with time, despite the turnover in participants; (4) on average the characteristics of the plots censused are constant over time; and (5) variability of map interpretation can be eliminated with training.

Internal Constraints

Any census scheme may seek either to obtain absolute estimates of population density, as pairs breeding per unit area, or to obtain measures of relative abundance. For the CBC the absolute census efficiencies for each observer and species are unknown. Hence, absolute densities cannot be computed (though see below), and only relative abundances can be established. Relative abundance measures should ideally be related to density by a linear function of the form

$$D_j = a_j I_j + b_j$$

where D_j is the density of birds on the plot j, I_j is the relative measure of the species' abundance on the jth plot, and a_j and b_j are constants. Since these constants are, in general, species-, plot-, and observer-specific, relative densities can be compared neither across species nor across plots. Changes in density are correctly indexed over time, though, provided census efficiency remains constant from year to year. This applies even if the values of the coefficients a and b are unknown.

In the CBC scheme, data from many census plots are collated to yield an overall index, and the resulting confidence intervals are therefore realistic, though based on certain assumptions. Since the percentage change from year 1 to year 2 is independent of the particular census efficiency a_j of the jth observer, constancy of observer efficiency is essential. Were the same observers to continue censusing the same plots in the long term, no further safeguards would be necessary. In practice some 19–24% of the observers leave each year, and replacement observers and plots must be recruited to maintain the scheme. In practice, too, the number of plots in the scheme in a given year may vary. These operational features of the scheme impose the additional requirements that the characteristics of observers and the characteristics of their plots on average do not change over time.

These assumptions have been supported by examinations of the internal statistical consistency of the CBC data (Taylor 1965; Mountford 1982) and by a field experiment in which four observers who differed significantly in individual census efficiency and in duration of their census visits were found to remain adequately consistent in these respects over the 2 years tested (O'Connor 1981c; O'Connor and Marchant 1981). Although the duration of the sample consistency has been studied less, it has been shown to be at least 5 years for several species (Mountford 1982, 1985). This time-span will ensure significant turnover of observers and suggests that requirements for average observer efficiency are met and remain consistent. A major limitation to such checking is that farmland management in Britain changes rapidly in response to technical and economic developments (O'Connor and Shrubb 1986), and apparent breakdown in consistency may reflect these changes.

Despite these checks, the average size of farmland plots sampled has decreased markedly (about 32%) between 1961 and 1980 (Fuller et al. 1985). Because small plots have a greater edge effect than larger plots (Marchant 1981; Verner 1985), this downward drift in average plot size could introduce some bias into the CBC index, a possibility which has not been checked. The composition of the CBC sample with respect to land class, cropping regimes, and regional distribution did not vary significantly over this period.

These features of the CBC allow some types of analysis but preclude others. First, analysis of single year changes across species are valid. O'Connor (1981a) showed that after the extraordinarily severe winter of 1962–63 in which many resident birds died, the 1983–84 population increases of the species involved were well correlated with their annual egg production. Second, analyses of temporal trends are valid, and several such studies have been undertaken. Because the CBC index does not track the national population accurately, the plots being nonrandomly distributed, such analyses need to involve large-scale phenomena to be successful. Winstanley et al. (1975) documented a marked decline in the number of whitethroats (*Sylvia communis*) breeding in Britain. This was based on CBC data and due to drought in the Sahelian zone of Africa, where much of the population winters. O'Connor and Mead (1984) have similarly documented the eightfold recovery of stock dove, *Columba oenas*, following the introduction of controls on the use of persistent organochlorine compounds in Britain. Alternatively, the spatial bias can be acknowledged and controlled by suitable choice of regional samples, a procedure used successfully by O'Connor and Shrubb (1985, 1986).

One limitation to using CBC index values is that the values for all species were arbitrarily set to 100 in the 1966 base year. (Actually, certain species were too scarce in 1966 to appear in an index in that year and have been assigned other base years.) Hence, the index values cannot be used to compare numbers across species without first finding some way of estimating their species-specific density multiplier in the base year, though their relative changes can validly be compared. To estimate absolute densities from CBC data, the census efficiency coefficients (a_j and b_j) ideally should be known for each plot. However, if variation in these coefficients across plots is small relative to the variation in bird numbers between plots, absolute densities can be obtained on the basis of an independent estimate of the average value of a. Experimental evidence suggests that the number of clusters found for each species using the CBC method may not vary greatly between observers. Among four observers, the lowest total of clusters recorded (all species combined) was 70% of the largest cluster (O'Connor 1981c), though the size of this effect varies between species (O'Connor and Marchant 1981). This can be compared with the more than two-fold variation in numbers across species recorded in Hickling (1983).

Cluster totals for a plot can only approximate population size there. Spurious clusters may arise at shared feeding sites; territories may be large relative to the census plot; registrations may be typically diffuse, especially with secretive species; double registrations of the same bird on a single visit may occur; and multiple sightings of birds in conflict or in parties may be difficult to interpret (Fuller and Marchant 1985). Nevertheless, in a field trial, Snow (1965) showed that for most species a census based on eight visits gave good approximations to the population actually present. Other studies based on the international mapping method lend some support to this conclusion (Diehl 1974; Enemar et al. 1979; Tomialojc 1980; Verner 1985), some suggesting that good agreement between mapping and estimates made with marked birds or with playback has been obtained only through chance balancing of errors. In the one overview of existing studies published to date, territory mapping and independent assessment of the number of breeding pairs present were correlated across species from 0.69 to 0.97 (O'Connor and Marchant 1981). The use of CBC clusters probably ranks densities fairly well, but may not be absolutely accurate as an indicator of absolute densities (Svensson 1980; Dawson and Verner, unpublished report). A particular problem not yet adequately addressed for the CBC is whether observers "saturate" (and therefore underestimate) in the presence of high densities of birds, as demonstrated by Bart and Schoultz (1984) in the United States.

On the assumption that cluster densities from the CBC scheme are adequately indicative of real densities, variations in numbers between plots or classes of plots can be investigated in relation to plot characteristics. Osborne (1982) used this technique to demonstrate the effects of Dutch elm disease on farmland bird populations in Britain, and O'Connor (1981b) used it to examine habitat correlates of farmland birds. Wilson (1977), Williamson (1967), and O'Connor and Shrubb (1986) likewise used the approach to compare regional densities of birds. The census maps for individual plots can also be overlaid on the corresponding habitat maps to identify habitat correlates of bird distribution (Williamson 1968,1970).

External Constraints

The CBC is extremely labor-intensive, both in the field and in the office. For example, in 1982, some 360 participants spent about 13,000 h in the field and generated about 14,000 species maps in about 6,000 h of subsequent collation (O'Connor and Fuller 1984). At the BTO the scheme each year requires the service of four scientific and two clerical–secretarial staff. The time of the participants is given voluntarily, but staff are salaried under a contract from the Nature Conservancy Council. Most of this staff time is devoted to the map interpretation involved. With four analysts involved, even moderate staff turnover results in one post being under training at any one time, and the resulting cross-checking of analyses also slows down output of the trainer. Yet this training is the key to the successful use of the mapping method. O'Connor and Marchant (1981) and O'Connor (1981c) showed that inexperienced workers do not follow the written rules of map interpretation closely enough to avoid significant between-analyst variation. This was also the case in studies by Svensson (1974) and Best (1975). However, training successfully eliminated this problem (O'Connor and Marchant 1981).

The large staff commitment to this aspect of the CBC severely limits the possible output from the scheme, given the existing budget. Automated cluster analysis has been advocated (North 1977, 1980) to save manpower, but the algorithms previously available have been unsatisfactory (Wragg 1982; O'Connor and Fuller 1984): their computation was poorly behaved and involved a heavy computing load; they required calibration by species and habitat against manual interpretations; and they ignored much of the qualitative information in the registrations. Map digitization also proved as costly in time as manual interpretation. Sheffer (1987) has since published details of a new clustering algorithm which seems to overcome the difficulties listed previously. Sheffer's algorithm has been tested for 16 species and yielded extremely good agreement with manual assessments of the territories present, even without drawing on qualitative information contained within the registrations. If this technique proves applicable to the CBC results, it will remove the need for highly trained analysts to undertake map interpretation. It might also remove the current need for observers to collate visit maps to species maps, because visit maps could be digitized directly and the registrations collated by species using appropriate computer programs. Scheffer's work may prove to be a major breakthrough in reducing the manpower cost constraints on the use of the CBC scheme data and opening up the possibility of extensive analysis of spatial patterns for which the BTO data set is uniquely suitable.

Acknowledgments

This paper is based on work undertaken while I was Director of the British Trust for Ornithology, and it was funded under a contract from the United Kingdom Nature Conservancy Council. My participation in the Patuxent Wildlife Research Center workshop was funded by the U.S. Fish and Wildlife Service. I am grateful to both for their financial support. The comments of several anonymous reviewers are also appreciated.

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Part II: Methods of Trend Analysis

Papers in Part II of the workshop reflect some of the controversies that surround the estimation of population trends from long-term surveys. Unfortunately, it is often unclear what constitutes a trend. Dagum and Dagum (1988) divide time-series into four components: a trend, cycles, seasonal variations, and irregular fluctuations. They define the trend as the component that "corresponds to sustained and systematic variations over a long period of time," which is "associated with the structural causes of the phenomenon in question, for example, population growth . . . ." The surveys considered in this workshop are all relatively short-term, and it is difficult to estimate a trend that is independent of either short term fluctuations associated with weather or other cyclic components of population change.

Also, ecologists are often interested in examining components of population change other than trend, and in this case an estimate of trend does not provide an adequate description of regional population changes. An underlying theme of several papers was the notion that trends are of little use in characterizing the dynamics of populations, and that composite yearly indices for regions must also be estimated to provide insight into the other components of the time-series. It is our opinion that the notion of estimating a long-term trend for a population is relevant because a population cannot persist indefinitely with a consistently negative trend. The difficulties arise in determining if a real trend exists in a short-term data set, or if the trend estimate is actually modeling another component of the time-series. Regional annual indices of abundance provide a context for the trend estimates that allows this determination.

Several approaches to estimating population trends and regional annual indices of abundance were discussed in the workshop. In general, these approaches can be categorized as (1) methods that estimate regional yearly indices of abundance and use the indices to infer population trends, or (2) methods that estimate population trends first, and then annual indices of abundance are estimated in the context of the population trends.

Unfortunately, for route surveys such as the North American Breeding Bird Survey, each route contains attributes, such as years with missing counts and observer changes, that make simple yearly averages of route counts biased estimates of yearly indices for a region (Geissler and Noon 1981). Consequently, most of the annual index methods discussed in the workshop proposed (1) smoothing route data (using LOWESS methods, which accommodate missing data but not observer differences) and then calculating regional yearly averages, (2) estimating regional indices using linear models to adjust for missing yearly data and observer differences, or (3) estimating regional yearly indices from variation remaining after variation associated with the regional trend has been removed.

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Topics in Route-regression Analysis

by

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ABSTRACT.—The route-regression method has been used in recent years to analyze data from roadside surveys. With this method, a population trend is estimated for each route in a region, then regional trends are estimated as a weighted mean of the individual route trends. This method can accurately incorporate data that is unbalanced by changes in years surveyed and observer differences. We suggest that route-regression methodology is most efficient in the estimation of long-term (>5 year) trends, and tends to provide conservative results for low-density species.

Introduction

The U.S. Fish and Wildlife Service (FWS) and the Canadian Wildlife Service coordinate several large-scale roadside surveys that are designed to monitor population changes in breeding bird species. Two of these surveys, the Woodcock Singing-ground Survey and the Mourning Dove Call-count Survey, are the primary sources of information regarding the population status of these hunted populations, and are analyzed yearly as part of the process of setting hunting regulations for these species. The third survey, the North American Breeding Bird Survey (BBS; Droege 1990), provides population information for more than 400 avian species in the United States and Canada.

All of these surveys were established in their present forms during the 1960's. Since these surveys were established, there has been ongoing research regarding proper methods of analysis for the rather specialized experimental designs of these surveys. Recent research centers on finding a reasonable statistic for population change over an interval of interest. In this paper, we briefly outline the constraints on the analysis of these roadside surveys, the current method of analyzing the surveys, and some of the issues associated with the present analytical method.

Constraints on the Analysis of Roadside Surveys

Several of the papers in these proceedings discuss the biases associated with roadside survey data (e.g., Droege 1990). Roadside surveys all share a design in which the sampling unit is a route with several stops. After the initial random selection, the same routes are run each year. Unbalanced data results from relocating routes, observer changes, and missing counts. Each year, some routes are not run, and routes are added and deleted from the surveys in all years. Unless the analysis compensates for the lack of balance, the counts can give the spurious appearance of increasing or decreasing regional means (Geissler and Noon 1981). By changing observers, variability is introduced in the counts because individuals differ in their hearing, knowledge of bird identification, and ability to follow survey procedures. When a new observer surveys a route, stop locations may change, so not only does a different individual conduct the route, but the actual area surveyed often changes slightly. These observer differences can cause great changes in count data from year to year for both American woodcock (*Scolopax minor*) and mourning doves (*Zenaida macroura*; D. D. Dolton, personal communication; J. B. Bortner, personal communication).

Route-regression Analyses

To circumvent the difficulties discussed previously, the FWS supported the development of methods of determining population trends from roadside survey data. In recent years, the route-regression method has been used to estimate the rate of population change over an interval of interest. While this goal may not always be appropriate, due to population cycles or abrupt population changes (e.g., James et al. 1990), careful application of the methodology is useful for most management applications. The route-regression methodology was developed elsewhere (Geissler and Noon 1981; Geissler 1984; Geissler and Link 1988); we will summarize the method and discuss some of the issues associated with its application.

The route-regression methodology is based on the notion that "trend" can be estimated as the ratio: (population in the midyear +1 of the interval)/ (population in the midyear). If there are no missing counts and if observer differences are negligible, the ratio can be estimated directly from the regional total counts. If there are missing counts, route changes, or if observer differences are important, regional totals cannot be used because each route will contribute inconsistent data to the total. Instead, regional trends can be estimated as weighted averages of the route trends. A linear model is used to estimate the trend for each route, adjusting for the differing abilities of observers.

The route-regression methodology involves the following steps.

1. Fit a multiplicative model to each route:

$$C_y = b_0^y \, b_1^{o_{1y}} \, b_2^{o_{2y}} \ldots b_n^{o_{ny}} \varepsilon_y \,, \qquad (1)$$

where

C_y = count in year y,
b_0 = slope term,
b_i = observer coefficient for observer i ($i = 1, \ldots, n$),
o_{iy} = 1 if observer i ran route in year y, = 0 if not.

In practice, the model is fit using a linear regression on the logarithm of (counts + 0.5), for example:

$$\ln(C_y + 0.5) = \ln(b_0)y + \ln(b_1)o_{1y} + \ldots + \ln(b_n)o_{ny} \,.$$

The estimate of $\ln(b_0)$ is back-transformed (Bradu and Mundlac 1970) to find an estimate of b_0 on the route. The back-transformation is approximately $\exp\{\ln(b_0) - 0.5\,\widehat{\mathrm{variance}}\,[\ln(b_0)]\}$ and compensates for the skewness of lognormally distributed counts.

2. Estimate the regional trend as a weighted mean of the route trends

$$\bar{b} = \frac{\sum_s A_s \sum_{r=1}^{n_s} \tilde{C}_{sr} \hat{b}_{sr} w_{sr}}{\sum_s A_s \sum_{r=1}^{n_s} \tilde{C}_{sr} w_{sr}} \,, \qquad (2)$$

where

A_s = area of stratum s,
n_s = number of routes in stratum s,
$\tilde{C}_{sr}$ = marginal mean count for the route (Searle et al. 1980),
$\hat{b}_{sr}$ = estimated route trend (b_0 indexed by stratum and route), and
w_{sr} = weight discussed below.

For BBS data, we use physiographic regions within States as our strata. The marginal mean (also called a least squares mean) is the mean count in the midyear adjusted for observer differences. The product $(\tilde{C}_{sr}\hat{b}_{sr})$ is the adjusted count in the following year according to the model (1). If the weight $w_{sr} = 1/n_{sr}$, routes have equal weight and (2) reduces to

$$\bar{b} = \frac{\sum_s A_s \tilde{C}_{s\cdot(\bar{y}+1)}}{\sum_s A_s \tilde{C}_{s\cdot\bar{y}}} \qquad (3)$$

where $\tilde{C}_{s\cdot y}$ is the mean adjusted count for the stratum in year y, and $\bar{y}$ represents the midyear. If the weight used is $w_{sr} = \widehat{\mathrm{variance}}[\ln(C_{sry} + 0.5)] \,/\, \widehat{\mathrm{variance}}[\ln(\hat{b}_{sr})]$, each route is weighted inversely by the relative variance of the route trend estimate. This weight depends only on known values (the years the route was run and the identity of the observer) and not on the estimated variance. Each stratum is effectively weighted by the number of routes and number of years they were run as well as by the stratum area. If the weights are standardized so that $\sum_r w_{sr} = 1$, strata are weighted only by area and not by the amount of survey effort.

If the interval of interest is 2 years, then equation (2) extrapolates beyond the last data point, which overemphasizes population increases. For 2 years we use the ratios of counts including only the routes that were run by the same observer:

$$\bar{b} = \frac{\sum_s A_s \sum_{r=1}^{n_s} C_{sr(y+1)} / n_s}{\sum_s A_s \sum_{r=1}^{n_s} C_{sry} / n_s} \,. \qquad (4)$$

This equation differs from (2) in using actual counts instead of adjusted counts in year y (the first year of the interval) and $y + 1$.

3. Estimate variances by bootstrapping the regional slopes ($\bar{b}$). This is accomplished by randomly selecting a bootstrap sample of n_s routes with replacement from the n_s routes in each stratum, and estimating $\bar{b}$ for that bootstrap sample. We repeat this procedure 400 times and estimate the trend and its standard error by the mean and standard deviation of the bootstrap sample estimates. The median can also be used to estimate the center of a skewed distribution. Recent work suggests that there is little difference between the mean and the median, and consequently the more commonly used mean may be preferable (Geissler and Link 1988). Either a t or z value can be used to estimate confidence intervals. If t value is used, the number of degrees of freedom is the number of routes minus the number of strata groups. If z values are used, we do not assess statistical significance for States or Provinces with < 10 routes, or for larger regions with < 25 routes.

Advantages of Route-regression Methods

Incorporates Unbalanced Nature of Routes

Route-regression methodology can use routes that were not run for some of the years of interest. Routes that are incomplete are weighted less heavily in the regional averages, reflecting the lower value of these data. In the singing-ground and call-count surveys, routes on which no birds were counted for 2 (or 3 for the call-count survey) years are considered to be "constant zero routes" and are not run for the next 5 years. They are then run, and if no birds are counted they are placed back into constant zero status. Although this procedure saves effort, it effectively creates a "not run" category that has in the past been considered as zero counts. Some controversy has existed regarding the proper analysis of constant zero routes, and it has been suggested that including them could produce a spurious decreasing trend (S. L. Stokes, unpublished memo). The route-regression method places these routes in their proper context as low-density routes that have little influence on regional population trends.

Proper Variance Estimation

The route-regression method obtains estimates for the variances of regional estimates of trend from the route trends. Earlier methods first estimated yearly indices of abundance for the regions, then modeled the trends from these indices. Variances for the population trends were then a function of the variation among the yearly indices, and the between-route variation was not incorporated. Because we are estimating population trends, the consistency of trends among the routes is the appropriate source of variation to consider in the analysis, and the route-regression method correctly incorporates this.

Use of Covariables

The route-regression method provides a framework in which sources of variation at the route level can be identified and incorporated into the analysis. We currently assume that observers perceive birds at different levels, but that all observers record the same changes over time. Therefore, a covariable can be included for observers that scales the line at different levels for each observer. In addition, if disturbance (e.g., number of automobiles heard during the survey period) is measured on a route, it can also be included in the analysis as a covariable, with some additional assumptions.

Topics in Route-regression Analysis

Critiques of the Methodology

Since the route-regression method was developed, there have been several reviews of the methodology, most noticeably that of D. W. Hayne of North Carolina State University. In response to the reviews, the method has evolved to its current form, which is presented here. One reoccurring criticism of the methodology concerns back-transforming the slope estimate to provide an unbiased estimate of $\bar{b}$ in equation (1). The present Bradu and Mundlac (1970) method is efficient if the estimate is unbiased, but may not be the appropriate estimator if the slope estimates are biased. D. S. Robson (personal communication) suggested a direct, iterative method of solving equation (1) that avoids both the back-transformation and the necessity of adding a constant to the count (which allows it to be log transformed). Unfortunately, this method does not converge in a variety of common cases, including the case in which no birds were recorded on the first year a route was surveyed. Model-based annual indices are not available for that model, although residual indices could be used.

Biases Associated with Small N *Years*

A variety of simulations have been conducted using route-regression methodology. One topic that has been addressed is biases in the method. By simulating routes with various underlying distributions of counts and numbers of years run, one can assess how the route-regression method performs under a variety of reasonable situations that occur in nature. These simulations are described by Geissler and Link (1988):

however, we provide some guidelines for the use of the method based on the simulation results.

1. Short-term (<5 year) trends may provide biased results. In general, the trend method was designed to provide estimates of long-term population trends.
2. The magnitude of positive or negative population trends tends to be underestimated for birds that are observed at low densities on survey routes.
3. Addition of observer covariables effectively reduces the number of years a route was run, as trends are estimated within observers. Hence, observer changes on a route effectively decrease the accuracy of the estimates derived from the route.

Acknowledgments

We thank C. M. Bunck, S. Droege, R. M. Erwin, and J. D. Nichols for comments on the manuscript.

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Estimation of Annual Indices from Roadside Surveys

by

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ABSTRACT.—Most of the surveys presently used to estimate population trends on a large geographic scale depend upon repeated visits to a number of randomly selected routes or monitoring points. As these surveys cannot be analyzed by modeling annual mean densities among routes within a region, no natural annual index of population density exists for the region. We discuss two possible methodologies for estimating annual indices of abundance. In the context of the route-regression methodology, in which trends are estimated for each route and regional population trends are estimated as weighted averages of route trends, it is possible to find average residual distances between the predicted trends on each route and the actual data points. Adding these average residuals to the regional predicted values provides a measure of average distance from the actual data points to the predicted trends. A linear model approach can also be used to estimate annual indices, in which a regional slope parameter can be fit to the data in combination with annual effects. Bootstrapping can be used to provide some measure of the variability of these annual effects. These methods provide similar results in an example using Breeding Bird Survey data for scissor-tailed flycatcher (*Tyrannus forficatus*) trends in Arkansas and Oklahoma.

Introduction

Because of the extensive effort necessary to accurately estimate the size of even a local population of birds, almost all large-scale avian surveys (such as the North American Breeding Bird Survey [BBS; Robbins et al. 1986]) use a sampling scheme that involves revisiting a permanent monitoring site (route) at yearly intervals and surveying birds with some consistent method. This approach provides precise estimates of population change because comparisons can be made within sites, removing the site-to-site differences from the variance. The reduction in variance thus obtained is analogous to reductions in variances that occur when a paired *t*-test is used as an alternative to a simple *t*-test. The annual procedures used to derive counts from each route vary in accuracy from territory mapping procedures designed to census numbers of breeding males (Breeding Bird Census; Johnson 1990) to a series of 3-min stops along a predetermined route (BBS; Droege 1990). In all of the surveys, however, the counts are not a census of an area but only provide an index to the actual population abundance (see Bart and Schoultz 1984 for a discussion of the ramifications of using an index to abundance). Often, observer differences and variation in coverage (some routes are not run each year) bias the annual average counts in a region. Because of these constraints, important biases can arise from population trends that are modeled directly from annual average counts from roadside surveys (Geissler and Noon 1981; Robbins et al. 1986). Modern trend estimation methodologies have attempted to circumvent biases associated with observer differences and inequities of coverage (Geissler 1984; Geissler and Sauer 1990).

The base-year method was formerly used by the U.S. Fish and Wildlife Service to analyze roadside survey data. In this method, changes from year to year are estimated for comparable routes, and annual indices of abundance are found by multiplying the density for a base-year by the year-to-year changes. Trends are then found using linear regression on the annual indices. The trends are modeled directly from the indices; hence, the trend line is an optimal fit to the index values and the values provide a measure of the fit of the line. This procedure can produce acceptable indices of abundance under some circumstances; however, if used over a series of many years it can produce spurious results caused by propagation of errors (Geissler and Noon 1981).

The route-regression method, which was developed to circumvent some of the statistical problems of the base-year method, does not provide the natural indices of abundance that are provided by the base-year method. Instead, it provides an estimate of population change over any interval of interest (Geissler and Sauer 1990). Trends are modeled using linear regression analysis for each route, incorporating observers as covariables to account for differences in ability to perceive birds. Route trends are in turn weighted to form regional trend estimates. This weighting creates difficulties in developing annual indices, as no natural index of abundance exists for this weighting scheme.

To place this weighted estimate of population change into a proper perspective and begin to examine possible causes for population changes, it is necessary to examine annual indices of abundance (e.g., James et al. 1990). We present two alternative ways of incorporating annual information into the general framework of the route-regression method. Both methods are discussed, comparisons are made between the methods, and examples of each are presented using BBS data for scissor-tailed flycatchers (*Tyrannus forficatus*).

Residual Method

Description

The residual method was developed in an attempt to provide estimates of population trends and annual indexes of abundance that are complementary. In the base-year method, population trends were modeled secondarily from the annual indices produced in the primary analysis. In the route-regression method the primary product is an estimate of population trends, and it seems reasonable to model the annual indices in the context of the population trend. The method must allow for variation in route and bird densities and in observer abilities. Because statistical significance is not assessed from these annual indices, the indices are primarily useful as a portrayal of year-to-year variation around the predicted trend line. Although the annual indices allow visual examination of patterns, all prediction of change points, intervals of increase or decline, and so forth must be viewed in the context of exploratory data analysis, and verification of observed patterns must be done using the route-regression method with appropriate adjustment of significance levels.

Because the route-regression method is based on linear regression methods, a natural annual index of abundance can be based on the residual variation between the predicted values from the regression and the actual annual count data. The route-regression methodology produces a regional slope estimate ($\bar{b}$) by first estimating individual route trend for any route (b_r) from the regression of annual counts (C_{yr}) on year (y) and observer covariables (o_{iyr}):

$$C_{yr} = b_{0r}^{y} b_{1r}^{o_{1yr}} \ldots b_{nr}^{o_{nyr}} \varepsilon_{yr} .$$

Taking logarithms,

$$\ln(C_{yr} + 0.5) = \ln(b_{or})y + (b_{1r})o_{1yr} + \ldots + \ln(b_{nr}) o_{nyr} + \ln(\varepsilon_{yr}),$$

where

r = route index,
C_{yr} = count in year y,
b_{or} = slope term,
b_{ir} = observer coefficient for observer i,
o_{iyr} = 1 if observer i ran the route in year y, 0 if not, and
ε_{yr} = random error.

$\mathrm{Ln}(b_{or})$ is back-transformed (Bradu and Mundlak 1970) to provide an estimate of b_r (the route trend) on a route.

Regional trends ($\bar{b}$) are estimated as a weighted mean of route slopes (Geissler and Sauer 1990). For BBS data, we use State physiographic stratum units as our primary regions of analysis. All population trends, no matter what the geographic scale, are estimated from combined ratio estimates of stratum trends.

To find the annual indices of abundance for a region, re-run the regressions for each route in the region, fixing the predicted regional trend as the slope parameter, and storing the resulting residuals for each year. Calculate the mean residual for each year. Find the predicted regional trend line (on a log scale, see below). Finally, add the mean residual to the predicted annual count (from the trend line) and exponentiate the sum to produce the annual indices. In the notation used previously:

1. First calculate a weighted regional estimate of trend ($\bar{b}$) and an average density of birds on all routes over all years ($\bar{c}$).
2. For every route r in the region of interest:
    a. "Fix" the regional slope, and calculate the observer effects using:

$$C'_{yr} = \ln(C_{yr} + 0.5) - \ln(\bar{b})*y = \ln(b_1)o_1 + \ldots + \ln(b_n)o_n + \ln(\varepsilon_{yr}).$$

b. For each year in which the route was run, calculate a residual:

$$e'_{yr} = C'_{yr} - \hat{C}'_{yr} ,$$

where $\hat{C}'_{yr}$ is the predicted value from the regression in (*a*).

3. Calculate the mean residuals for each year ($\bar{e}_y$) over all the routes in the region of interest.

4. Find the predicted trend line by setting the predicted count in the midyear equal to the regional grand mean count ($\bar{C}$), then multiply (or divide) by the estimated regional trend to calculate indices for later (or earlier) years:

$$T_y = \bar{C}, \quad T_{y+1} = T_y * \bar{b},$$

and

$$T_{y-1} = T_y / \bar{b}.$$

5. Calculate the annual indices by adding the mean residual to the logarithm of the predicted counts and exponentiating the sum:

$$I_y = \exp\left(\ln(T_y) + \bar{e}_y\right).$$

Note that no weighting scheme is used in finding the average residual, and no back-transformation other than exponentiation is used in the derivation of the indices. Further refinements of the methodology could incorporate some back-transformation such as that of Bradu and Mundlak (1970).

Advantages

Because the method was developed to provide estimates of annual indices in the context of the estimated population trends, residual indices have several advantages over alternative methods. The analysis complements the trend analysis, and one does not present separate analyses for trends and indices, which can be inconsistent. They are conceptually simple: you set up the predicted trend and use the average residual variation to compute the annual data points. If a route is not run in a year, no residual is calculated; hence, only data for the year of interest are incorporated into the estimates, and sample sizes of routes run in a year are readily observable. Since the analysis is done on the logarithmic scale and not back-transformed until the annual indexes are estimated, differences in scale among routes are not as great a problem as they are with analyses using actual densities (although they are still a component of the analysis and can potentially be a difficulty).

Disadvantages

Residual indices have the underlying assumption that the trend estimate from the route-regression methodology provides a valid estimate of change in the population. The indices present a visual display of whether, on average, the residuals of routes run in a year are above or below the trend line given by the regional trend estimate, and of the relative distance of the residuals from the predicted trend line. Consequently, if one has little confidence in the validity of the trend estimate, it is unlikely that the annual indices derived from the data will be of use. There are several cases in which predicted trends (and therefore residual indices) should be viewed with caution. We present two such pathological cases.

1. Large (but nonsignificant) estimates of regional trend. Point estimates of rapid increases or declines that contain a large amount of variability indicate little consistency in population trends among routes, and may indicate that many routes were not run consistently throughout the interval of interest. These large changes tend to distort population estimates at extreme points in the interval of interest.
2. Large variation in densities among routes. If large variation in route densities occurs (as is often the case with seabird colony surveys; see Engstrom et al. 1990), or large differences in counts occur within routes between years, the inclusion of a route can influence the magnitude of a residual value. These large differences in scale are difficult to incorporate into any analysis, and should be avoided by either poststratifying the data set and estimating trends separately for large colonies and small colonies, or by treating the large colonies individually. Unfortunately, there are some data sets which are too unbalanced (in years in which routes were run or in differences in density among routes) for any trend–index method to provide useful results.

The residual method was developed with the intent of providing annual indices that are primarily descriptive. No statistical significance is assessed with regard to the annual indices, but they provide a measure of how far (on average) the data values were in a particular year from that predicted by the regional trend.

Linear Model Method

Description

Another approach to the estimation of annual indexes of abundance involves fitting a linear model to all the data for a region, and then using the estimated model to calculate predicted counts for each route and year, adjusting for missing counts and observer differences. The model usually includes terms for each observer and route to reflect differing observer abilities and different habitat conditions along the routes. Thus population changes are measured by comparing the counts made by the same observer on the same route. Year effects are included to model stratum-wide population effects such as the effect of severe weather on recruitment, and route trends are included to model local habitat effects. Covariables, such as the effect of noise or other disturbance, can also be included to make the model more realistic. The usual model is:

$$C_{ry} = b_r^y d_1^{0_{r1y}} \dots d_n^{0_{rny}} f_1^{a_1} \dots f_m^{a_m} \varepsilon_{ry}$$

Taking logarithms,

$$\ln(C_{ry} + 0.5) = \ln(b_r)y + \ln(d_1)o_{r1y} + \dots + \ln(d_n) \cdot o_{rny}$$

$$+ \ln(f_1)a_1 + \dots + \ln(f_m)a_m + \ln(\varepsilon_{ry})$$

where

b_r = slope coefficient for router,

di = observer coefficient for observer i,

o_{riy} = 1 if observer i ran route r in year y, 0 if not,

f_y = annual effects coefficient for year y,

a_y = 1 if year y, = 0 if not, and

ε_{ry} = random error.

The predicted count $\tilde{C}_{ry}$ on route r in year y can be estimated as

$$\ln(\tilde{C}_{ry}) + \ln(\hat{b}_r)y + \ln(\bar{d}) + \ln(\hat{f}_y)$$

(Searle et al. 1980) and then backtransformed (Bradu and Mundlak 1970). It represents the predicted count for the average observer on route r in year y. The means of the predicted counts weighted by strata areas A_s provide annual indices of abundance:

$$I_y = \frac{\sum_s A_s \sum_r \tilde{C}_{sry} w_{sry}}{\sum_s A_s} ,$$

where W_{sry} are weighting factors reflecting the amount of information (inverse of the relative variance) available for estimating $\tilde{C}_{sry}$, normalized to sum to 1.0.

Advantages

Linear model indices use an analysis of covariance to fit observer and year effects to the survey data, and they account for missing counts, differing observer abilities, local habitat trends, large-scale population fluctuations, and other factors. The model is used to estimate predicted counts for each route and year whether the route was run or not. This yields a complete set of counts that have been adjusted for the differing observer abilities. The mean annual counts reflect relative densities of birds in the stratum. Weighting the relative densities of the strata by the strata areas produces population indices.

Thus the linear model method uses as realistic a model as possible to produce counts that might have been obtained under the ideal situation with complete data and with the same observer running the route every year. Once these predicted values for the ideal situation are estimated, the analysis is straightforward, as the mean counts are natural measures of relative density.

Disadvantages

The linear model indices may not fit a trend line estimated using route-regression methods as closely as the residual indices, as the regional trend parameter in the linear model is estimated differently from the route-regression trend estimate. However, conducting this separate analysis may be useful, as it can provide a slightly different view of the trends in bird populations. If the two methods provide greatly different results, it would indicate that a more detailed analysis is necessary. Unfortunately, the disadvantages associated with the residual indices also apply to linear model indices, as a rapidly changing or variable population will always be difficult to model.

The improvements associated with the linear model come at considerably increased computational cost. We have difficulty fitting the linear model, even within moderately large State physiographic stratum areas, as large amounts of memory are necessary for inverting the $(X'X)$ matrices. In addition, the linear model has to fit many parameters. If observers change frequently or if there are many missing counts, the parameters may not be estimable, and it may be necessary to simplify the model, possibly by not adjusting for observer differences.

Examples

We present two examples of the alternative index methodologies from the scissor-tailed flycatcher data set presented elsewhere in this volume. Arkansas and Oklahoma were selected for analysis (Figure) for 1967–87. Over the interval, the route-regression method

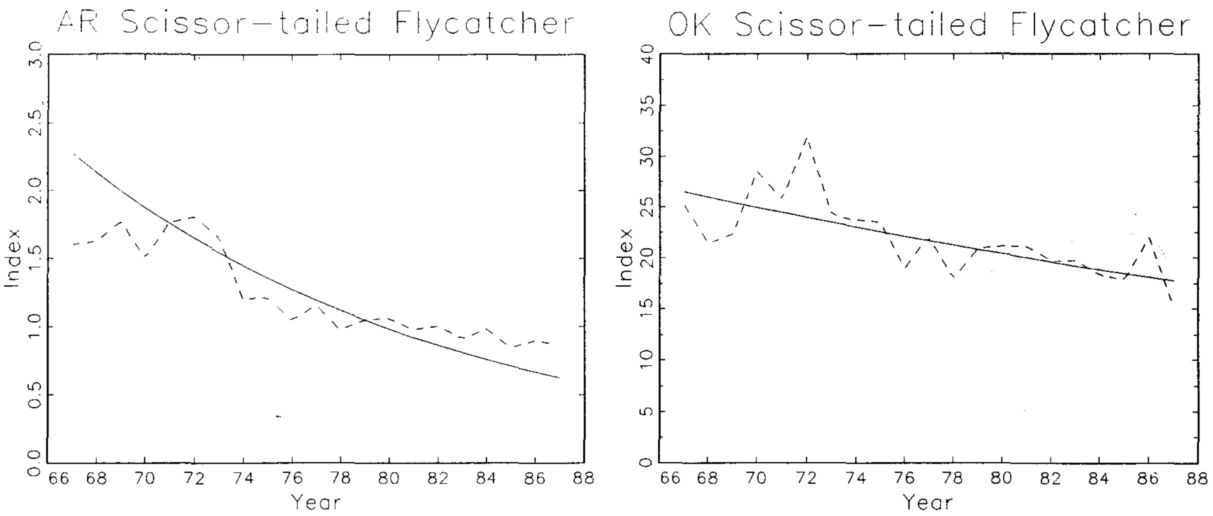

Figure. Predicted population trends and annual indices for scissor-tailed flycatchers (*Tyrannus forficatus*) for Arkansas and Oklahoma from BBS data. Predicted trends from the route-regression method, residual indices, and linear model indices are presented for 1967–87.

indicated significant declines in both States. Both annual index methods showed similar overall patterns for the interval, with population peaks reached in 1972, followed by declines until about 1978, after which the population generally increased in both States. The year-to-year changes indicated by the methods did not always match, with the most significant difference being a slight decline indicated by the residual method between 1984 and 1985, but a large increase suggested by the linear model index between the years.

Discussion

The estimation of annual indices has proven to be controversial. In current methods, no natural indices exist for trend analyses with $N > 2$ years, as observers change and routes are not consistently run. We have presented two methods, both of which have certain features that make them plausible indices. Because both types of indices seem to be similar, the extra computation cost of computing linear model indices may not be necessary.

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Using Rerandomizing Tests in Route-regression Analysis of Avian Population Trends

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ABSTRACT.—This paper discusses several aspects of the route-regression method of analysis of avian population trends. First, route-regression methods require that observed counts, y, be transformed by $\ln(y + c)$. A simulation study on the effect of different values of c on the estimate of population trend is described. Choosing $c = 0.23$ provides a more robust estimate of trend than $c = 0.5$ when the population count per route is small. Second, weighting factors for each route can be chosen in several ways. Some of the different choices selected by different authors are described. Third, the standard method of assessing the significance of the estimated trend from a route-regression analysis of an avian population survey is through a jackknife or bootstrap test to assess the consistency of the route trend estimates over the study region. An alternative method of assessing significance is through a rerandomization test which compares the trend to the magnitude of the within route variability. The situations in which these two methods are appropriate are contrasted. Fourth, the results of the route-regression method can be presented as slopes in the log scale but this is difficult to interpret. Alternative methods of presentation, such as half-lives or yearly decline rates, are shown. The results are illustrated with examples from the Southern Ontario Waterfowl Survey.

Notation

The analysis presented here is based on the method introduced by Geissler and Noon (1981), and the notation is similar but simplified to eliminate the physiographic strata within a Province or State. Let y_{ij} denote the jth observation on route i, and x_{ij} denote the year this observation was taken. The y are transformed to $z_{ij} = \ln(y_{ij} + c)$, where c is a constant to be discussed later. The reasons for selecting this transformation are described in Geissler and Noon (1981) and Collins and Wendt (1989).

A simple regression of the z_{ij} against the x_{ij} is performed, providing an estimate ($\bar{b}_i$) of the trend over time for route i. The individual route trends are aggregated to provide an overall estimate using a weighted average

$$b = \sum_{i=1}^{n} w_i \bar{b}_i \Big/ \sum_{i=1}^{n} w_i ,$$

where w denotes the weight given to route i and n denotes the number of routes.

The weighting factor w is a product of three terms: an area weight f_{1i}, a measure of the precision of the trend estimate f_{2i}, and a measure of the average population index for the route f_{3i}. These terms are described in more detail below.

Selection of the Constant in the Transformation

A simulation study was conducted to assess the influence of the parameter c in the transformation $\log(y + c)$ and to determine if a value of c existed which yields estimates with a controlled maximum level of bias.

It was assumed that the number of birds recorded on a route was described by a negative binomial distribution. Under this model the probability of observing y individuals is

$$\frac{k(k+1)\dots(k+y-1)}{y!}p^{y}(1+p)^{-y-k}$$

where k and P are parameters of the distribution. The mean and variance of this distribution are

$$E(y) = kP = \mu, \text{ and}$$

$$V(y) = kP(1+P) = \mu + \mu^2/k.$$

Thus for fixed μ, as k increases the variance declines. As k goes to infinity the distribution approaches a Poisson distribution.

In the simulation it was assumed that the mean observed count in plot i and year j was

$$\mu_{ij} = \exp(A + Bj).$$

Under this model a log transformation of the mean would show a linear trend with time, an underlying assumption in the route-regression technique. Inclusion of the parameter c in the transformation, and the inherent asymmetry of the negative binomial distribution, biases the regression estimate of B.

The effect of the added constant c is greatest when the population level is low. Simulations were done for a variety of populations levels given by initial mean counts per plot of one, two, three, four, and five individuals.

The variance of the population is controlled by the parameter k. To study the effects of the choice of c under different populations, the simulations were done with k equal to 2, 5, and 10. The variances of the initial population level for these choices of k are shown in Table 1. It can be seen that the variances vary widely with k, especially for populations with large mean counts. The variance for a Poisson distribution ($k = \infty$) is also shown in Table 1. For initial mean population levels of 1, 2, or 3, increasing k beyond 10 would not appreciably reduce the variance of the distributions.

The simulation was done for trends which had half-lives of 5, 10, and 20 years. These rates correspond to annual changes of 12.9%, 6.7%, and 3.4%, respectively. These changes are rapid but are within the range of values seen in actual data presented later.

The effect of the additive constant was examined for c equal to 0.1, 0.2, 0.3,..., 1.0. These values were chosen to include both the value 0.5 recommended by Geissler and Noon (1981), and to have an upper limit of 1.0, which was anticipated to cause a substantial bias in the estimate of trend for populations with low counts.

The simulation was run for two cases: 10 routes visited for 10 years and 50 routes visited for 10 years. The simulation used the same set of random numbers for each set of parameters within each case but different random numbers for the two cases. This was done to reduce the influence of random variability in the comparisons among parameters. The simulations were run using a FORTRAN program on an IBM-AT. Each simulation was run 1,000 times.

The results of the simulation are displayed in Fig. 1 for the 50-plot case, with the negative binomial parameter k set to 2, the half-life equal to 50, and the initial population densities of 1, 2, 3, 4, and 5. The results for the other simulations were similar and are not displayed. The numbers at the end of each curve denote the population size. It can be seen that the parameter c influences the estimate of trend substantially, especially for small population sizes. As would be expected, the slope of the lines declines as the population size increases. The horizontal dashed lines indicate the actual trend plus and minus 10%.

Table 1. *Variance of initial population levels used in the simulations.*

Initial mean count per plot	Negative binomial parameter k			
	2	5	10	∞
1.0	1.5	1.2	1.1	1.0
2.0	4.0	2.8	2.4	2.0
3.0	7.5	4.8	3.9	3.0
4.0	12.0	7.2	5.6	4.0
5.0	17.5	10.0	7.5	5.0

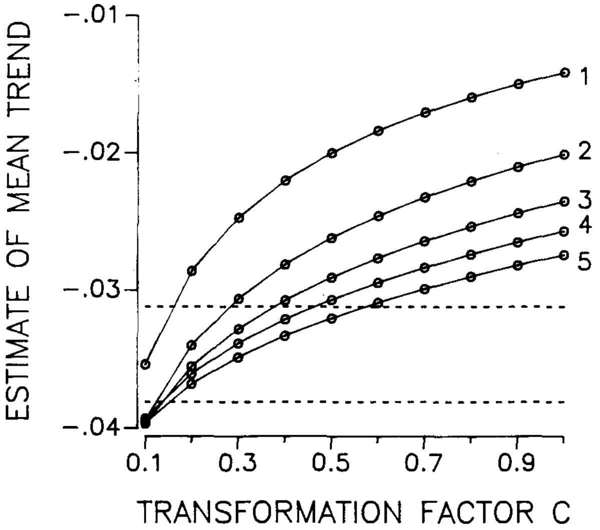

Fig. 1. Mean estimates of trend based on 1,000 simulations of 10 years of data from 50 routes with half-life of 20 years. Negative binomial parameter k = 2, for initial population densities of 1, 2, 3, 4, and 5.

The values of c, where each curve of the type shown in Fig. 1 equaled the true value plus or minus 10%, were calculated using linear interpolation. Thus for each curve a range of values of c which introduces a bias of less than 10% was calculated. These ranges are shown in Fig. 2. The vertical dashed line on the graph is at c = 0.23, which was the value selected by Collins and Wendt (1989) to control the bias.

No simulations have been done for populations greater than five individuals per route because the influence of c decreases with increasing population size. For populations of five birds per route, setting c to 0.5 would introduce a bias of less than 10% for many situations. As the population size increased the influence of c would decline even further, and setting c equal to 0.5 could be conjectured to not introduce substantial bias in the estimated trend.

The simulations have been done only for declining trends. However, due to the symmetry of the solution to the regression equation, the results can be seen to also apply to an increasing trend if the years were numbered in reverse order.

It is obvious that introducing too large a value for c would tend to minimize the estimated trend over time and produce estimates which are biased toward zero; however, using too small a value for c can bias the trend estimate away from zero (Fig. 1). Consider what happens when there is a declining trend. It is substantially more likely that positive counts at the beginning of the time-period will be followed by one or more zero counts near the end of the time-period than that the reverse will occur. The estimate of slope for such a data set will be negative. As the value for c is reduced the transformed zeros will move farther away from the transformed positive values and the slope estimate will become more negative. Eventually, as c is reduced, the preponderance of outcomes of this type will introduce a substantial bias in estimated slope.

Weighting of Individual Routes

The weighting factor w_i used for each route is composed of three terms as described earlier. The inclusion of the three terms in the weighting of the individual route regressions is common in many surveys, but the exact form of the terms can vary.

The area weight f_{ij} is a reflection of the area of the survey which the route represents. In the analysis of the Canadian segment of the Breeding Bird Survey (BBS) by Collins and Wendt (1988) the areas were calculated on a degree block basis, because the degree block was the primary sampling unit used to define the survey. The area of land and the number of routes run in each degree block were calculated, and each route in the degree

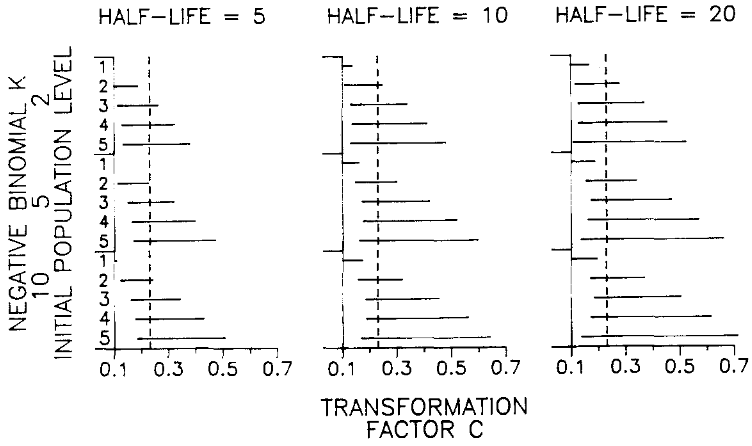

Fig. 2. Range of c for which the mean estimate of trend was within 10% of the true value based on 1,000 simulations of 10 years of data from 50 routes with half-lives of 5, 10, and 20 years. Negative binomial parameter k = 2, 5, and 10, for initial population densities of 1, 2, 3, 4, and 5.

block was assigned a weight equal to the area divided by the number of routes. This analysis covered the period 1966–83. Because the population trends might not be described by a linear trend over the entire period of the survey, the analysis was repeated for five selected subperiods: (1) the most recent 5 years, (2) the period before the most recent 5 years, (3) the most recent 10 years, (4) the period before the most recent 10 years, and (5) the entire survey frame. The number of routes run varies among the subperiods analyzed, and hence the area weight had to be recalculated for each subperiod. In some instances there were no available routes within a degree block, and the block was not included in the analysis. This means that comparison of trends among subperiods can be confounded with differences in area of coverage. Other analyses have resolved this problem by pooling contiguous degree blocks to ensure complete coverage of the survey region (Erskine 1978), but the selection of the blocks to be amalgamated was subjective. This problem of intermittent coverage of degree blocks by the BBS causes particular difficulty in defining the northern limit to the range covered.

Robbins et al. (1986), in their analysis of the BBS, used physiographic regions within a State or Province to define sampling units, rather than degree blocks. The physiographic regions tend to be substantially larger than degree blocks, particularly within Canada, and hence may always have a suitable route within each subperiod. This would then avoid the difficulty in comparing subperiods with different areas of coverage. This procedure, however, ignores the distribution of the routes within the physiographic regions. The routes are often more clustered close to major urban areas and less concentrated in the remote areas. Giving all routes within a physiographic region the same weight could produce an estimate that is weighted towards the areas in which routes are run.

The precision of the individual route estimates of trend (b) varies among routes because the number of observations on each route varies. Under the usual assumptions made in regression analysis, the variance of the estimate of trend for an individual route is given by

$$V(b) = \frac{\sigma_i^2}{\sum_{j=1}^{m}\left(x_{ij}-\bar{x}_i\right)^2}$$

where m is the number of observations on route i, σ_i^2 is the variance of an individual observation, and $\bar{\chi}_i$ is the average year of observation for route i.

The variance term σ_i^2 is unknown and may vary among routes, but it could be estimated from the difference between the observed and predicted counts. However, the number of observations on a route is too small to provide reliable estimates of variance. Hence σ_i^2 is assumed constant across routes and can be dropped from the slope precision term in the weighting factor. The slope precision term is set equal to the denominator in the above variance term. This is a different weighting factor than that proposed by Geissler and Noon (1981) who proposed the term

$$f_{2i} = \left[\left(m-1\right)\sum_{j=1}^{m_i}\left(x_{ij}-\bar{x}_i\right)^2\right]^{0.5} .$$

This was the weighting factor used by Robbins et al. (1986), but in another report, Geissler (1984) stated that the weighting should be proportional to the reciprocal of the variance, as is described in the previous paragraph.

The third term in the route weight is a measure of the population level for the route. The recommended estimator of this term also has been changing over time. The original form (Geissler and Noon 1981) of this term was

$$f_{3i} = \left[\pi_{j=i}^{m_i}\left(y_{ij}+c\right)\right]^{1/m_i}$$

$$= \exp\left[\sum_{j=i}^{m_i} z_{ij}/m_i\right] .$$

This is the geometric mean count for the observations on route i, except for the additive constant c, which is introduced to avoid multiplying by 0. This procedure ignores the number of years and the distribution of years in which the observations were taken. Thus for a route in which the population is changing, the weight given to the route varies depending on the years in which the observations were taken. For example, Fig. 3a shows two routes in which the population is decreasing. Route 1 was observed in years 1 and 2, while route 2 was observed in years 4 and 5. Under the scheme above, route 1 would receive a higher population weight than route 2. In Collins and Wendt (1989) the route population weights were based on the predicted population level in the midyear of the period under study. The predicted transformed count in the midyear, Z_{io}, would be

$$Z_{io} = \bar{Z}_i + b\left(x_0-\bar{x}_i\right)$$

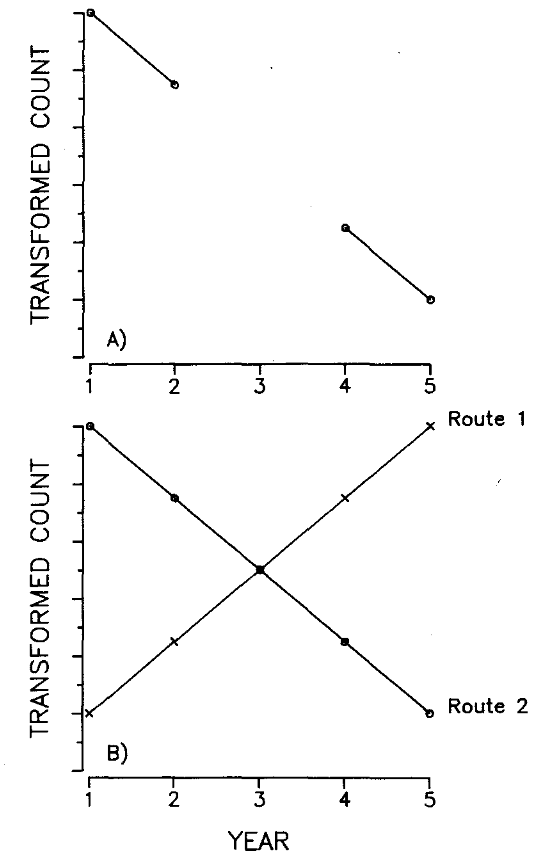

Fig. 3. Hypothetical trends illustrating effect of various population weighting schemes: (*A*) effect of routes being observed in different years, and (*B*) effect of different route trends.

which can be converted to a predicted count as

$$y_{io} = \exp\left(z_{io}\right).$$

The midyear was selected because it did not bias the results towards an increasing or decreasing trend. Consequences of misapplicaton of weights are best illustrated by extreme cases. For example, Fig. 3b shows two hypothetical routes with perfect linear trends and the same average population level, but with trends in opposite directions. If the predicted count in year 1 was used, then route 1 would be given a higher weight and the overall trend would be downward, while if the final year were used, route 2 would be given a higher weight and the overall trend would be downward. In this example, selecting the initial year (giving higher weight to a route which exhibits a decline) biases the combined estimate of trend towards predicting declining populations and vice versa.

One problem with using predicted population levels at the midyear of the study to assign weights is that it can involve extrapolating beyond the range of years that observations are taken on a route. Some BBS routes were run for a few years and then dropped or were only initiated near the end of the time frame under study. The predicted values for the dependent variable extrapolated beyond the range of the observed independent variable have a large variance. The conversion of these values by using them as exponents can result in assigning unreasonably high weights to some routes. This problem can be reduced somewhat by Windsorizing the weighting factor. In Collins and Wendt (1989) the route population weights were Windsorized at 100, and in the Southern Ontario Waterfowl survey they were Windsorized at 50.

Geissler (1984) also has refined the route population term through a technique developed by Bradu and Mundlak (1970). This procedure is used to minimize the bias in a regression on a logarithmic scale.

Testing for Significance

The usual method of testing significance in the route-regression method is through a jackknife or bootstrap estimate of variance. This method assesses the significance of the overall trend through the consistency of the individual route estimates of trend. Whenever the trend is similar in direction and magnitude for the set of routes, the

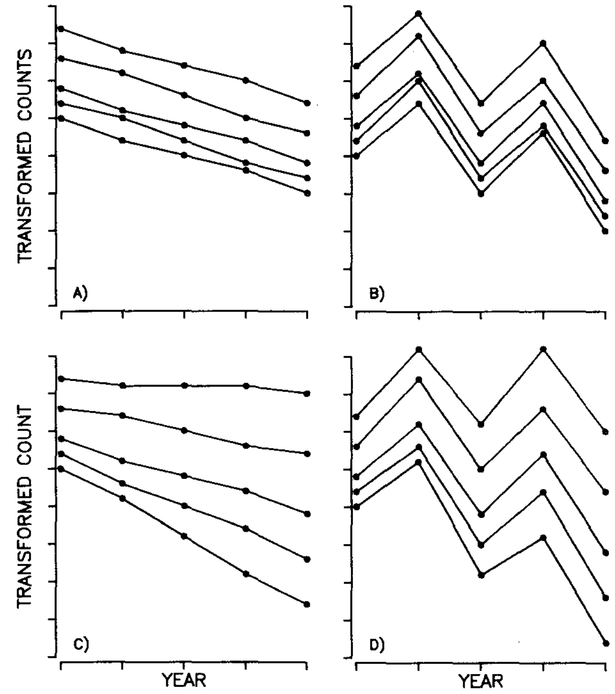

Fig. 4. Hypothetical trends illustrating how bootstrap and rerandomization tests would assess significances differently.

jackknife procedure will estimate the variance to be small and will lead to a conclusion of a significant trend. An alternative method to assess significance is through a rerandomization test. In this procedure the observations are randomly reordered separately within each route, and the test statistic is recalculated. The proportion of times in which the randomized trend statistic exceeds the observed one is an estimate of the probability the observed trend could have resulted when no underlying trend is present.

Figure 4 illustrates some hypothetical data for which the two procedures would provide different answers. Figure 4a indicates an ideal data set in which there is a consistent trend within a route over time and across routes. Figure 4b shows a situation in which the trend is consistent across routes, but there is a substantial amount of within-route variability. In Fig. 4c, the trend is consistent over time within a route, but varies among routes, and in Fig. 4d the trend varies among routes, and there is substantial within-route variability. The regression lines for individual routes are identical for Figs. 4a and 4b and, similarly, the individual regressions are identical for Figs. 4c and 4d.

Both procedures would find that the data in Fig. 4a indicate an appreciable trend, and that the data in Fig. 4d indicate a much less consistent trend. The jackknife procedure would assign equal significance to the trends in Figs. 4a and 4b despite the larger variability of the observations in Fig. 4b about the line. This is because it only evaluates the consistency of the trend. The rerandomization test would conclude that the trend shown in Fig. 4b was less significant than the one in Fig. 4a because it evaluates the variability of the data about the trend line. The jackknife procedure would find the trend in Fig. 4c less significant than the trend in Fig. 4a; however, the rerandomization procedure would find both to be of similar significance despite the among-plot variability.

The examples in Figs. 4b and 4d exhibit a substantial year effect, since the deviations about the trend line are similar for different routes in a given year. This would occur in situations where overall weather effects, such as severe winters or late springs, dominated the bird counts. In this situation both the jackknife and the route rerandomization would have a type I error rate above the nominal rate for the test. A correct rerandomization test in such a situation would involve randomly reordering yearly observations in parallel for all routes. Such a test would probably have a substantially reduced power to detect trends, and careful consideration would be required on how to handle missing observations.

Presentation of Results

The output of the route-regression analysis is an estimate of trend in the log scale. These values are not easy to grasp, nor is it easy to understand their biological significance. An alternative method of presentation would be to calculate the time required for the population to change by a given amount, such as a half-life or doubling-life, or to calculate the amount of change which would take place in a fixed period of time. This calculation is illustrated in Table 2, which shows results from the Southern Ontario Waterfowl Breeding Survey. For example, the estimated slope is 0.0327 for mallard (*Anas platyrhynchos*), which corresponds to a doubling-life of 21 years, a 58% increase over the 14-year period of the survey, a 3.3% increase per year, and a 39% increase in 10 years.

The estimated half-life and doubling-life should only be viewed as a means of interpreting the slope. This parameter is unstable when estimating trends which are close to zero. For example, a slope of 0.01 has a doubling-life of 31.6 years, while a slope of –0.01

Table 2. *Estimated trends in southern Ontario waterfowl, 1971–85.*

Species	Estimate of slope in log scale	Doubling or half-life	Percentage change: Over period of survey	Percentage change: Per year	Percentage change: Over 10 years
Canada goose	0.1543	d 5	+ 767	16.7	376
Wood duck	0.0440	d 15	+ 85	4.5	55
Mallard	0.0327	d 21	+ 58	3.3	39
Common merganser	–0.0021	hgn[a]	–3	–0.2	–3
Ring-necked duck	–0.0030	hgn	–4	–0.3	–3
Blue-winged teal	–0.0085	h 81	–11	–0.8	–8
American black duck	–0.0672	h 10	–61	–6.5	–49
Green-winged teal	–0.0725	h 10	–64	–7.0	–52
Common goldeneye	–0.1253	h 5	–83	–11.7	–71

[a] hgn = half-life greater than 99.

has a half-life of 31.6 years. The presence or absence of a single bird might be enough to change the slope between these two values, which would be considered unremarkable if the slope were analyzed, but would produce a substantial change in the half-life calculation, which might be interpreted as biologically significant by an unsophisticated reader. Biologists also may find reported half-lives or doubling-lives that are longer than the period of the study to be difficult to interpret.

The percentage change over the period of the study is a useful description of the magnitude of the trend, but cannot be compared between studies which cover different periods. This can be avoided by calculating the percentage change for a fixed period. The percentage change per year is a more interpretable variable, but the objective of the analysis is to estimate long-term trends. Hence reporting the percentage change over 10 years may be more appropriate.

In Table 2 the species are sorted by the estimated slope, which enables the reader to assess the change for each species with respect to the others and to evaluate the number of declines compared with the number of increases. This is possible because only nine waterfowl species are analyzed, and locating a species of interest remains easy. For the BBS this might not be practical because of the large number of species and the greater taxonomic diversity.

Another possible presentation of the data is to plot individual routes on a map, with increases and decreases indicated by different symbols. Estimates of trend for each route were averaged for 20-min blocks and are shown in Figs. 5 and 6 for American black ducks (*Anas rubripes*) and mallard. It can be seen that the areas where black ducks were located is mostly restricted to eastern Ontario, while mallards were located over a widespread area. For the black duck the decline in numbers

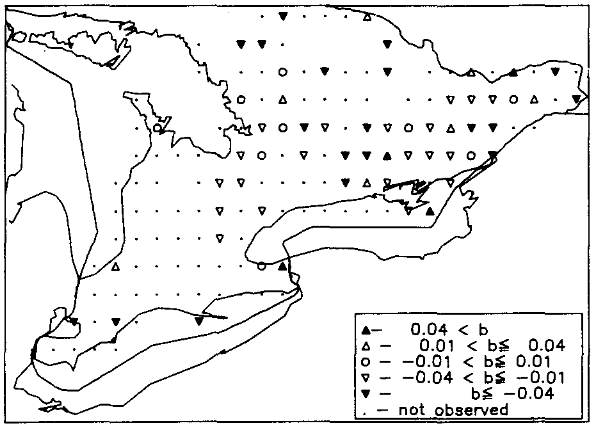

Fig. 5. Estimated trends in number of American black ducks (*Anas rubripes*) recorded in the Southern Ontario Waterfowl Breeding Survey, 1971–85.

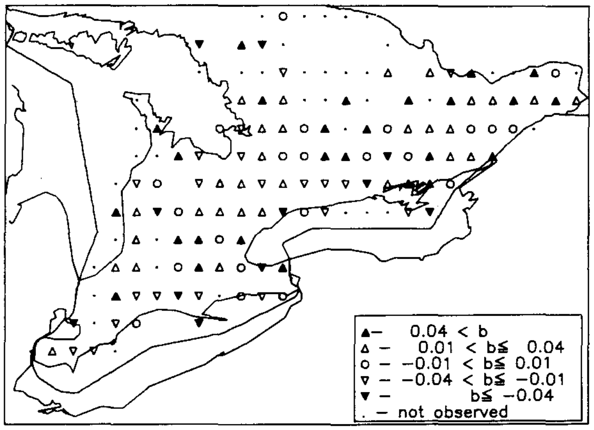

Fig. 6. Estimated trends in number of mallard (*Anas platyrhynchos*) recorded in the Southern Ontario Waterfowl Breeding Survey, 1971–85.

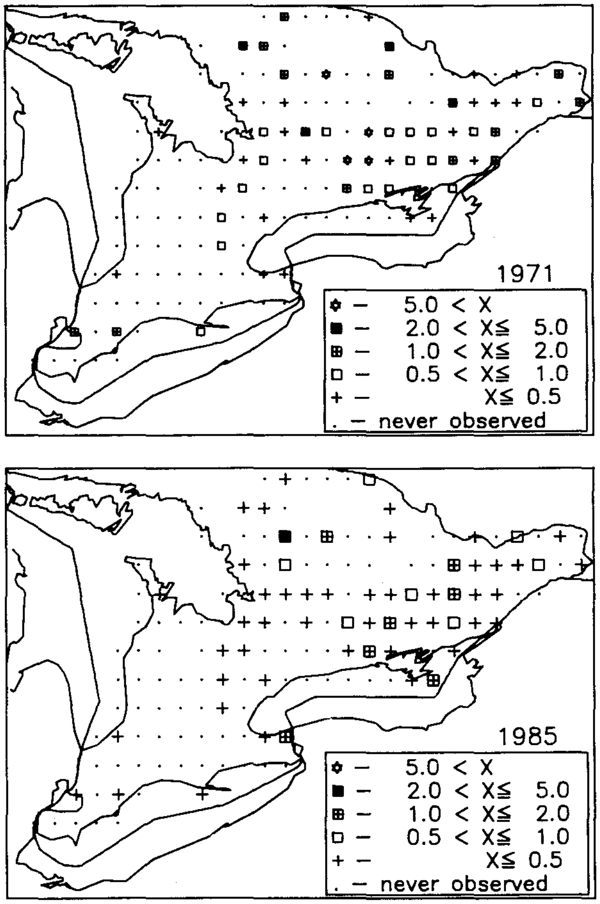

Fig. 7. Predicted numbers of American black ducks (*Anas rubripes*) on plots in the Southern Ontario Waterfowl Breeding Survey in 1971 and 1985.

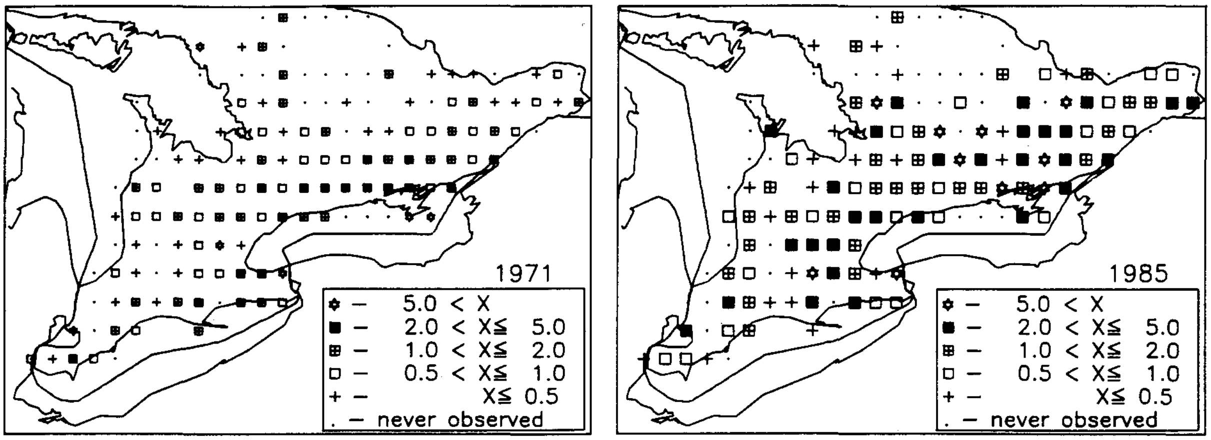

Fig. 8. Predicted numbers of mallard *(Anas Platyrhynchos)* on plots in the Southern Ontario Waterfowl Breeding Survey in 1971 and 1985.

throughout its range is evident despite the sporadic estimates of increases, but the change for the mallard is more difficult to assess because the areas of increase and decrease are not segregated. This may be due to the among-route variability of the estimate of trend and could be remedied through averaging over larger areas or through potential mapping.

Figures 5 and 6 do not indicate the magnitude of the population at each plotting position, which may cause difficulty in interpretation. Figures 7 and 8 show the predicted count per plot at the initial and final years of the survey for the same two species. The reduction in predicted black duck numbers throughout the range can be seen by comparing the two maps in Fig. 7, and hence the occasional increases in black duck numbers, which were seen in Fig. 5 no longer appear as discrepancies to this trend.

The maps shown in Fig. 8 show the general increase in mallard numbers across the study area and suggest that there may be a movement of the mallard away from the northern shore of Lake Ontario. Thus mapping of the data can reveal aspects of changes in the population which are not revealed by trend analysis.

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Estimating (Relative) Species Abundance from Route Counts of the Breeding Bird Survey

by

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ABSTRACT.—We propose and illustrate a method of estimating relative abundance of a species from Breeding Bird Survey data, with missing route counts, by iteratively fitting an additive row and column model to the logarithms of route counts. We point to the possible value of additionally fitting the first characteristic vectors in a singular value decomposition of the matrix of residuals from the row and column additive fit. Finally, we offer some reflections on whether to smooth (across time) the annual relative abundance results.

Introduction

For 21 successive years a set of routes, originally chosen as a probability sample of the United States, have furnished route counts of many bird species (Robbins et al. 1986). These counts have been obtained by a well-standardized observing process. Because of the probability-sample design it is possible to combine the route counts with known weights belonging to the design, and thus to construct a national abundance estimate for each species. Estimates for physiographic Provinces, or for other regions, such as States, can be similarly devised using the weights that belong to the routes in such a region.

Statistical problems arise in constructing the estimates. First, not every route is run every year. This complicates the estimation. Second, it may seem appropriate to smooth the annual abundance figures. How shall this be decided? How might it best be done?

This report treats these questions, and in the course of so doing considers also the possible desirability of estimating not the abundance of species (a number, like 13,500 or 1,060,000) but rather the relative abundance of the species, like 60% or 110% of usual.

One way of treating the missing data problem is to impute values for missing data, and then proceed with the analysis appropriate to complete data.

Imputation of Missing Values, and Estimation of Abundance

We begin by introducing notation, to help the reader (and the writers). We will always talk in terms of only one species, so it needs no representation in our argument, or in the expressions we shall use. So, for some one species, let the route count from route number i, in year t, be denoted:

$$r_{it} \; (i = 1, \ldots, R \,; t = 1, \ldots, T).$$

We have altogether R routes (this is a small number if the species is the Kirtland's warbler [*Dendroica kirtlandii*] and a large one if it is the great blue heron [*Ardea herodias*]), and we have T years of annual Breeding Bird Surveys (BBS).

The estimated species abundance in year t we write as

$$A(t) = \sum w_i r_{it} \,, \tag{1}$$

where the weights are given by the sample design, the r_{it} by the year's route counts. But some route counts are missing. Our approach will be to impute (estimate) those missing route counts, and then get the estimate in (1), where some of the r have been imputed.[1]

Imputation might be done by fitting a row and column model to the $R \times T$ data array. Such a model might be

$$(r_{it})^p = \alpha_i + \beta_t + e_{it} \left(\sum \beta_t = 0\right). \qquad (2)$$

In this expression p denotes a power like 1 (the original data) or 1/2 (the square root) or 0 (by a limiting argument, the logarithm).

Figure 1 shows plots of variance against mean for the data when the transformations $r_{it}^1, r_{it}^{1/2}, (r_{it} + 1/6)^{1/10}$, and $\ln(r_{it} + 1/6)$ were applied to scissor-tailed flycatcher (*Tyrannus forficatus*) data. Each point corresponds to one route, with the route's mean plotted horizontally and the variance of its 21 years' values plotted on the ordinate.

The constant 1/6 was added to each route count to avoid complications with route counts of zero. We believe that had we used 1/2 or 1 rather than 1/6 we would have arrived at nearly indistinguishable results; the choice of 1/6 is based on a recommendation in the recent literature (Mosteller and Tukey 1977).

We liked the weakness of the mean-variance association seen for the logarithmic transformation, and we liked it for other reasons which will appear. So we favored the model

$$y_{it} = \ln(r_{it} + 1/6) = \alpha_i + \beta_t + e_{it} \left(\sum \beta_t = 0\right). \qquad (3)$$

This model closely resembles one already in the literature (Mountford 1982).

We fitted the model by a technique known as "mean polish" (Mosteller and Tukey 1977:181–183), which proceeds iteratively. At the start zeroes are entered for missing values. A complete cycle first fits row averages, then computes the residuals, to which column averages are then fitted, and the new residuals are ready for beginning the next cycle. We obtained convergence in about six cycles. The method makes much smaller demands on computer memory than do conventional least-squares estimates (and associated imputed values for the missing data). It dates from the early days of the modern computer (Healy and Westmacott 1956). The method is evidently also applicable where the rows call for different weights (row averages can be calculated using those weights);

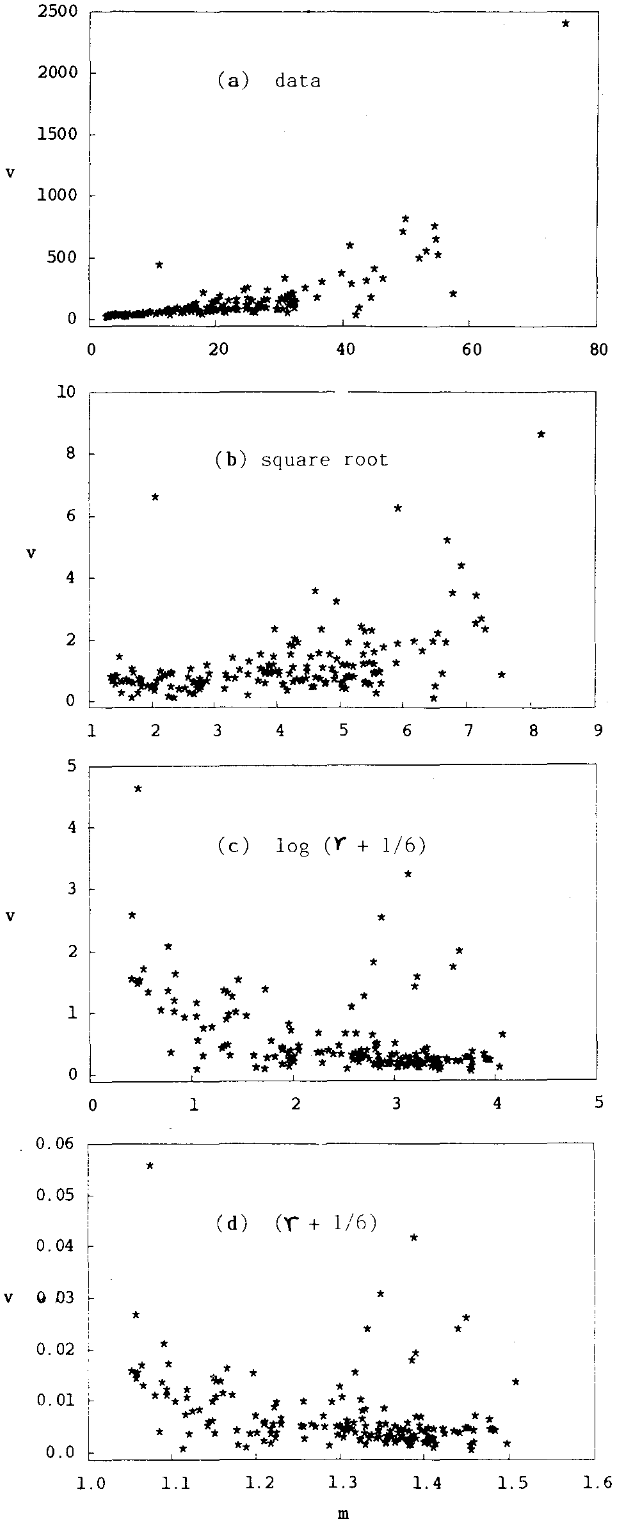

Fig. 1. Mean vs. variance for various transformations of the route counts: (*a*) raw counts; (*b*) square root of counts; (*c*) natural log of counts (increased by 1/6); (*d*) route counts increased by 1/6 and then raised to the power 0.1. (One point for each route.)

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[1] There are instances when this imputation approach coincides exactly with a method of "fitting the only data present." For example, in the usual analysis of variance situation the "missing value formulas" have just this character.

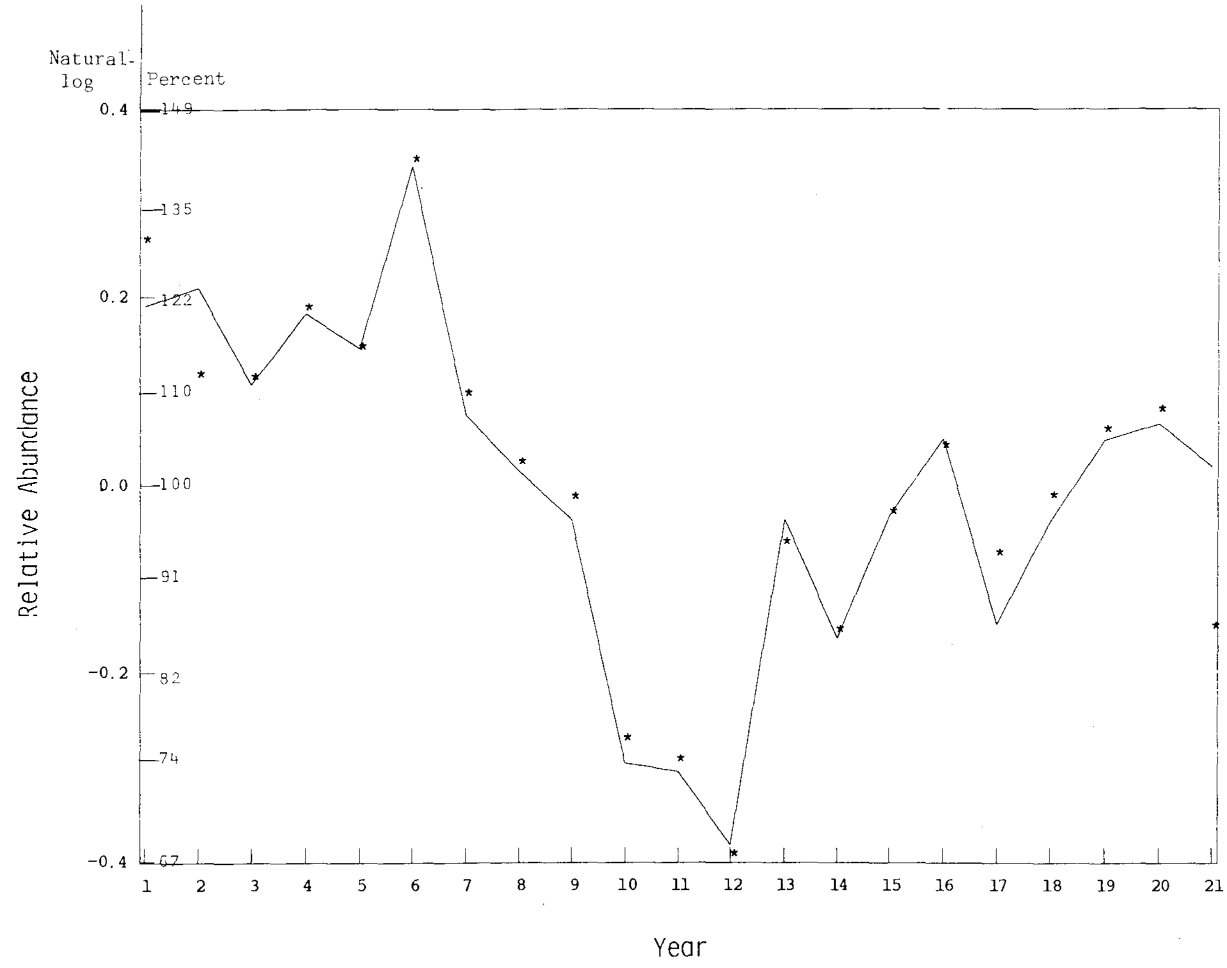

Fig. 2. Relative abundance of scissor-tailed flycatcher (*Tyrannus forficatus*; routes) with annual average exceeding 2.0, as estimated in two ways: *Stars* denote values fitted without reference to covariances; *line* shows estimates using sample covariances.

the method is closely related to the EM algorithm (Dempster et al. 1977).

The fitted value of $\ln(r_{it} + \frac{1}{6})$ for any missing route could then be back-transformed to an imputed value (somewhat biased), permitting $A(t)$ in expression (1) to be computed.

Now, analysis of variance routines are designed for situations where the error terms have homogeneous variance and zero correlations. Though we have helped with the former desideratum, by transforming to the logarithm, we would check the correlation among the residuals. What we found for the scissor-tailed flycatcher data were clearly significant correlations on routes between counts for nearby years. So we fitted the logarithmically transformed observations again, this time estimating the 21 by 21 covariance matrix between the residuals (from the row and column additive fit) for times t and t', and then used that estimated covariance matrix in fitting the parameters α_i and β_t. This fitting was accomplished by applying a form of the EM algorithm (Dempster et al. 1977). The results were almost unchanged! Figure 2 shows the values of $\hat{\beta}_t$ plotted for years 1 through 21 computed in the two ways; the stars show the $\hat{\beta}$'s from the EM algorithm; the vertices of the broken line show the $\hat{\beta}$'s from the direct analysis of variance program. Notice how close the two time series are; observe also that simpler estimates look like a slightly smoothed version of the EM result. We judge the two series to be unimportantly different, and are content to use the simpler estimation procedure, at least for the scissor-tailed flycatcher data.

Some further light is cast on this issue by Fig. 3, which presents again the simpler-fitted $\hat{\beta}_t$'s; this time each appears as a star. The broken lines show the highest and lowest values of $\hat{\beta}_t$ found in applying the simpler fitting procedure to 500 bootstrap samples from the 236

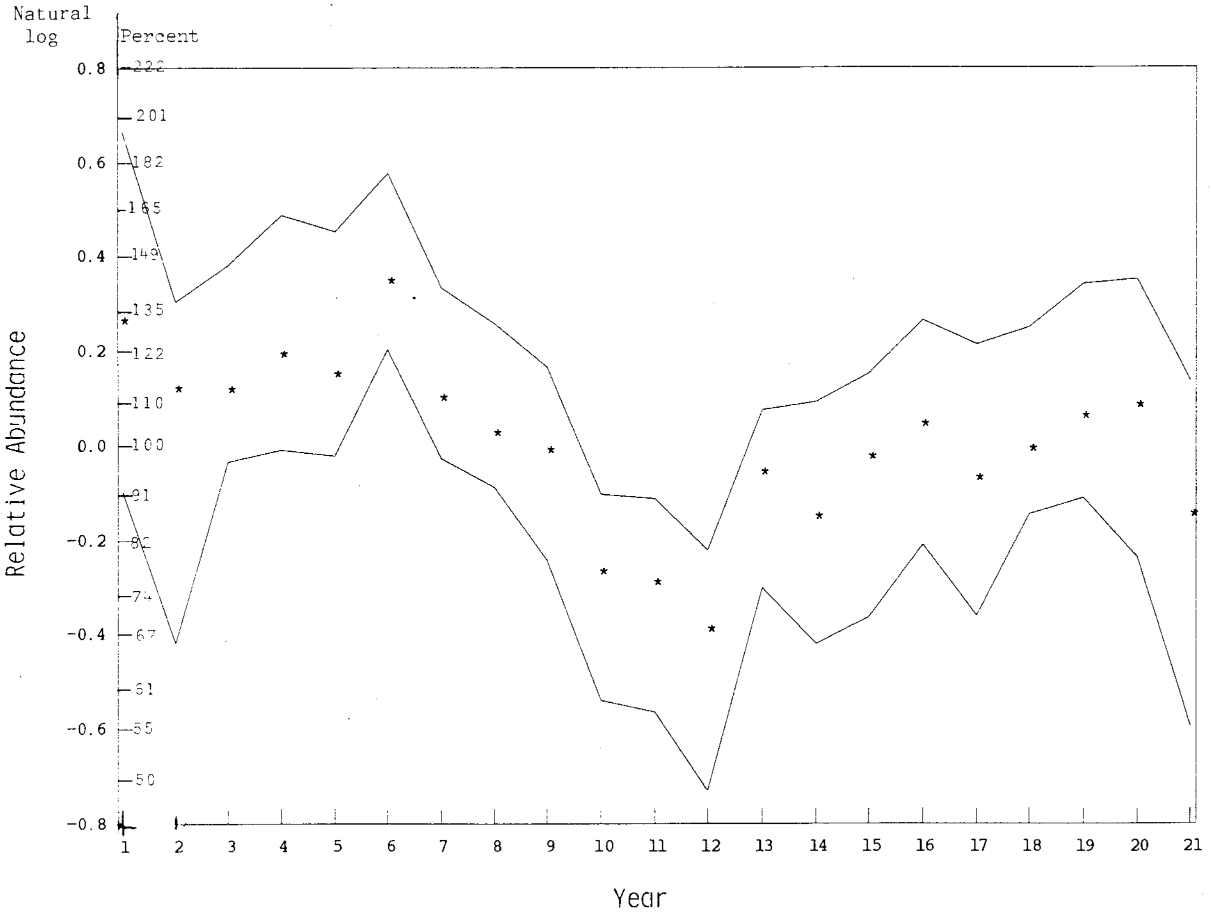

Fig. 3. Bootstrap variation of estimated relative abundance. *Stars* depict estimates using routes with average annual count exceeding 2.0: *Upper line* connects maxima of 500 bootstrap samples; *lower line* connects the minima. (Estimates did not use covariance structure.)

routes.[2] These outer lines give an idea of the variability of the estimates $\hat{\beta}_t$. In the light of that variability, we continue to regard as unimportant the differences from the two methods of estimation, one of which acts as if the inter-year correlations were zero, while the other takes them into account.

It is known that ordinary least-squares estimates of a correct additive model suffer inefficiency, but not bias, in the presence of correlations. So, with abundant data as here, we need not be surprised to see close agreement between two unbiased estimators of β_t. With fewer data, differences might be large, and we might prefer the EM algorithm.

Before going further we explain an important feature of the fitting procedure that we employed. Of the 236 routes with any positive counts for the scissor-tailed flycatcher, there were 71 that had very spotty data, in the sense that in the 21-year period the total counts observed did not exceed 42 (Table). These routes were omitted in the calculations that underlie Figs. 1, 2, and 3, and their accompanying text. The possible effect of omitting this part of the data set is probed in Fig. 4, which compares the estimates just referred to, with estimates in which all those omitted routes were included, but in the following way. For each of the nine States, the small routes were combined into one fictitious super-route; this increased R from 165 to 174. The eye is struck by the smallness of the differences between estimates that completely omit the 71 small routes and the estimates

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[2] The bootstrap analysis was performed by drawing with replacement, a sample of 165 complete route records for the 165 routes retained as having annual averages exceeding 2.0, and then analyzing the data of the bootstrap sample by the same program as applied to the main analysis.

Table. *Distribution of scissor-tailed flycatcher (*Tyrannus forficatus*) routes by State and route abundance. Routes with 42 or fewer species sightings in the 21-year period are counted as small; those with 43 or more are large. Observe that all counts on all routes appear in the tabulation of the right-most column, where one super-route aggregates all counts of the small routes.*

	Number of routes			
	Observed		Used in analysis	
State	Large 43 birds or more	Small 42 birds or less	Primary analyses	Including super-route
Arkansas	6	16	6	7
Iowa	0	1	0	1
Kansas	14	23	14	15
Kentucky	0	1	0	1
Louisiana	2	9	2	3
Missouri	3	11	3	4
New Mexico	1	2	1	2
Oklahoma	35	1	35	36
Texas	104	7	104	105
Total	165	71	165	174

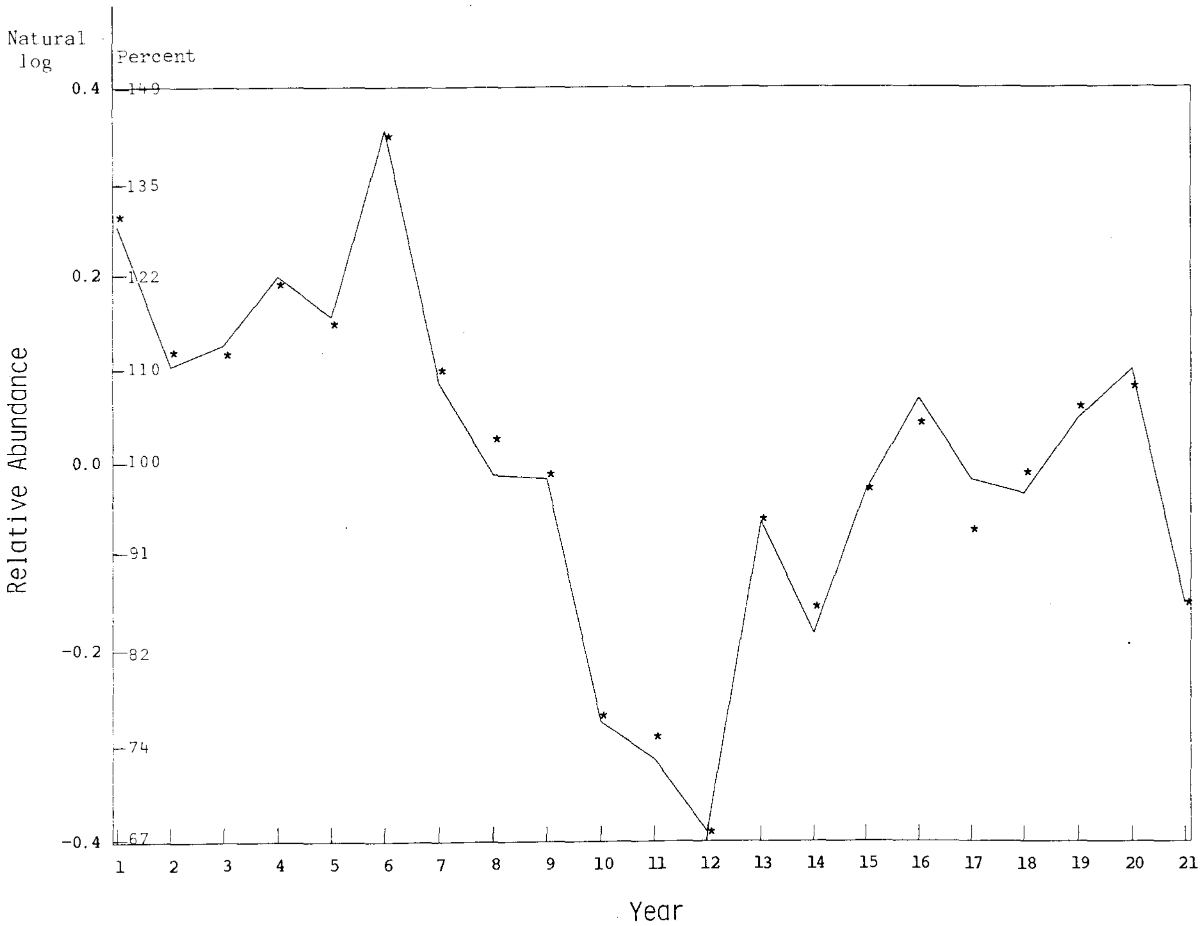

Fig. 4. Estimated relative abundance of scissor-tailed flycatcher. Estimates based only on routes with more than 2.0 annual average counts are denoted by ⋆. Estimates including for each State one super-route that combines all small routes in the State are denoted by the line.

that include them as fictitious State super-routes. Exploration with other species (and perhaps with other thresholds than 42) would further illuminate the suitability of this mode of dealing with routes offering meager data.

The distribution by State of small routes is displayed in the Table.

Estimation of Relative Abundance

In the previous section we showed how to estimate $A(t)$, the (absolute) species abundance in year t, by replacing the missing route counts with values from a logarithmic row and column model. If, as may be the case, total abundance is most interesting merely as a device to assess relative changes in abundance, then plotting the logarithm of $A(t)$ against t will render equal percentage changes as visually equal; thus 64, 80, 100, and 125, each 25% greater than its predecessor, would be equally spaced vertically in such a graph.

If relative abundance is itself the focus of interest, we need not do so much calculation, for the estimates $\hat{\beta}_t$ already developed in the two-way fitting can serve directly. Recall expression (3), which we repeat:

$$y_{it} = \ln(r_{it} + 1/6) = \alpha_i + \beta_t + e_{it} \left(\sum \beta_t = 0\right). \quad (3)$$

This leads to estimates $\hat{\alpha}_i$ and $\hat{\beta}_t$ and indeed to fitted values for the y_{it}, which we call $\hat{y}_{it}$

$$\hat{y}_{it} = \ln(r_{it} + 1/6) = \hat{\alpha}_i + \hat{\beta}_t \quad (4)$$

whence, exponentiating both sides, we get

$$\hat{r}_{it} + 1/6 = e^{\hat{\alpha}_i} e^{\hat{\beta}_t} = \hat{A}_i \hat{B}_t. \quad (5)$$

So, except for the addition of 1/6 to every route count, we find the fitted values of each route count (whether originally missing or not) represented in equation (5) as the product of a quantity $\hat{A}_i$ (the ith route's estimated overall abundance) and another quantity $\hat{B}_t$, the year's abundance factor. The original normalization $\sum \beta_t = 0$ implied that $\sum \hat{\beta}_t = 0$, and therefore that the product of all the $e^{\hat{\beta}_t}$ must be $e^0 = 1.0$. So the product of $\hat{B}_t$'s is 1.0; some are larger (in abundant years) and some are smaller. The product (and their geometric mean) is 1.0.

Thus we have a second, and more direct, solution to the estimation of relative abundance. Figures 2 through 4 display the fitted $\hat{\beta}_t$ (on the natural log scale) and the fitted $\hat{B}_t$ (on the percent scale).

If we wished to estimate relative abundance for a particular portion of the whole country (e.g., a physiographic Province), then a new consideration appears. The method in which we first estimate the absolute abundance allows us to calculate for each Province, p ($p = 1,..., P$), its abundance in year t as

$$A_p(t) = \sum_{(p)} w_i r_{it} \quad (6)$$

where the routes being summed over (with their weights) are the routes in Province p; the subscript (p) on the summation sign denotes that. Now these Province abundances add up to $A(t)$, since each route is in one of the Provinces and $A(t)$ uses them all. That is the consistency relation that this method possesses, and it enjoys this property exactly for complete data (i.e., no missing r_{it}). But, when some route counts must be imputed, some discrepancy—perhaps not important unless there is much incompleteness—arises between $\sum_p A_p(t)$ and $A(t)$, depending on whether the imputation is done separately for each Province or for all the data at one time.

When we go directly to relative abundance estimation through the $\hat{\beta}_t$, then separate fitting to the Provinces is natural, and the estimates, $\hat{\beta}_{t(p)}$, that result need not be equal, and the value of $\hat{B}(t)$ for the whole country is some kind of weighted average of the $\hat{B}_{t(p)}$, not easily described.

Thus we have two ways to estimate relative abundance for component Provinces: (1) from the whole-country model's estimates deduce absolute abundance and correct to relative abundance Province by Province; or (2) directly estimate relative abundance Province by Province. They are not equivalent, and it is not at all obvious what their relative merits are. The issue can be seen as two ways of handling any interactions of year with the routes belonging to different Provinces. To fix ideas, suppose there are two Provinces, U and V, and that relative abundance in U was high in early years, while in V it was high in later years. Except for the missing data fitting, the absolute abundance approach in effect obtains the overall estimates by using a certain weighted combination (resulting from the w_i of the sample design) of the two Provinces' estimates $\hat{\beta}_t^{(1)}$ and $\hat{\beta}_t^{(2)}$. If the weights are in some way inappropriate then the Provinces' abundances are consistently, but inappropriately, combined. On the other hand, the direct relative abundance approach would estimate the two Provinces' relative abundance parameters $\hat{\beta}_t^{(1)}$ and $\hat{\beta}_t^{(2)}$ separately in the two Provinces, which would be desirable, but how to combine the estimates into a national figure does not have an obviously best solution. (Many are possible. Perhaps they could be weighted in proportion to $\sum_{(1)} w_i$, and $\sum_{(2)} w_i$; that is, the sums of route weights in Provinces (1) and (2).) Notice that the second approach better reveals the different annual patterns of Provinces U and V.

Additional Comments and Discussion

1. We have said nothing about smoothing. The abundance estimates already have been purged of much randomness, by what amounts to averaging data across many routes. The bootstrap data in Fig. 3 admit the possibility that some smooth curve (indeed many possibilities offer themselves) could be passed within the uncertainty zone. But would such a smooth curve be closer to reality? This question really means "In fact, do bird populations change smoothly from year to year, or is there a lot of abrupt change at times?" If the latter proposition is true, then the value of smoothing becomes unclear.

The desirability of smoothing a time series seems to be greater when there are very many data points, and when the data must be regarded as quite "noisy." Suppose we observe $y(t)$, and it combines two components, a signal $g(t)$ and noise (e), thus

$$y(t) = g(t) + e(t).$$

If $e(t)$ has large variation, we can hope to see the signal $g(t)$ better by smoothing $y(t)$ – in effect averaging the $e(t)$ in some way to stabilize and reduce their influence. We many welcome this, even knowing that we have also averaged – and distorted – $g(t)$. But what if $e(t)$ has small excursion? Indeed, what if we knew $g(t)$? Might we still wish to smooth it? Maybe. Maybe we strongly prefer simpler paths in time, as easier to contemplate. Maybe we think of true but unusual changes in the value of $y(t)$ as transient and accidental, and wish to downplay them. The considerations are reminiscent of when to prefer a diagram or a painting to a photograph. We ourselves incline to the view that with only 21 time points, and those equally spaced, the eye can pretty well supply any needed smoothing or important trend identification. Of course, showing both the points and the smooth can be a good solution. But we have nothing to contribute here about preferred ways to smooth across time.

2. The relative abundance method calls for an annual refitting across all years and routes. This is a drawback. Shortcuts that call for less frequent refitting are not hard to develop, but we do not offer our results here, as they bring a lot of technical detail to what is really a subordinate problem.

3. The BBS data are quite extensive and may afford opportunity for revealing patterns of substantive interest, much beyond more estimation of relative abundance (or absolute abundance). We are indebted to J. Tukey for the ideas that follow. We learned them in a conversation with him while birding.

Return to the estimation model at (3),

$$y_{it} = \alpha_i + \beta_t + e_{it} \left(\sum \beta_t = 0\right).$$

Consider now augmenting it to the following more complex form

$$y_{it} = \alpha_i + \beta_t + \gamma_i \delta_t + e_{it} \qquad (7)$$
$$(\Sigma \beta_t = 0; \qquad \Sigma \gamma_i^2 = R).$$

Before going further we stop to understand just how we would interpret this model if (1) it were true and (2) we knew the values of the new parameters $\gamma_1, \gamma_2, \ldots, \gamma_R$ and $\delta_1, \delta_2, \ldots, \delta_T$. The γ's are rather straightforward to interpret. First, their squares average to 1.0, and so we will expect to regard 3 or –3 as a definitely large value and values between –1 and +1 as definitely not large. Second, two routes with the same value of γ_i tend to depart from the typical yearly pattern specified by β_t to the same degree, along the ("most relevant") time-distortion pattern, which is given by the set δ_1, $\delta_2, \ldots, \delta_T$. Third, two routes with equal and opposite γ_i depart equally, but oppositely, from the β_T's, and again with reference to the time-distortion pattern given by the set $\delta_1, \ldots, \delta_T$. Of course a route i with $\gamma_i = 0$ is one whose departure from the β_T's, though not necessarily zero, is uncorrelated with the modal time-distortion pattern. The set of δ's can be thought of as a pattern over the years. Perhaps it is high in the middle years and low in the early and later years, or maybe it is periodic, and so forth. In any case, our fitting (to be described later) will choose the pattern of δ's that obeys (7) and that most reduces the residual sum of squares left after the row and column additive fit of the α's and β's. So we may regard the set of δ's as the most relevant way in which routes tend to vary – either with that way or against it – from the overall average time pattern $\beta_1, \beta_2, \ldots, \beta_T$.

When we have the estimates $\delta_1, \delta_2, \ldots, \delta_T$, we might hope to relate them to El Nino years, shifts in the jet stream, and so forth. But having estimates $\gamma_1, \gamma_2, \ldots, \gamma_R$ may be more immediately fruitful. We might take a map and (using color coding) mark each route according to its $\hat{\gamma}$ value location on the net $-\infty, -3, -1.5, 0, +1.5, +3, \infty$. Perhaps the large positive values fall mainly on routes at high elevations, or in the south; perhaps there is a trend with seasonal rainfall, or date of last killing frost, and so forth.

It may well be that exploration of the use of the model (7) would justify the effort.

The computation proceeds in this way. First, fit the additive row and column model as previously described and compute Y, the R by T matrix of residuals. Then, to the T by T matrix $A = Y'Y$, apply an eigenvalue program. The largest eigenvalue λ_1 and its associated eigenvector a_1 are needed. The desired vector (δ_1 $\delta_2,...,\delta_T$) is in fact the eigenvector a_1. As shown in the Appendix, the R-vector $\gamma = (\gamma_1,\gamma_2,\ldots,\gamma_R)$, which may be very long if there are many routes, can be computed from Y, a_1, and λ_1 with little ado, as

$$\gamma = \sqrt{\frac{R}{\lambda_1}}Ya_1.$$

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Appendix

Let Y with R rows and T columns, $R > T$ be of rank K. Define $Y'Y = A$ and $YY' = B$. The singular value decomposition of A (Gabriel 1978) ensures that:

$$Y = \sum_{i=1}^{K} \sqrt{\lambda_i}\, b_i a'_i \tag{1'}$$

where (1) λ are the K non-zero eigenvalues of A (and also the K non-zero eigenvalues of B) and we order them so that $\lambda_1 \geq \lambda_2 \geq \ldots \lambda_K$; (2) a is the ith eigenvector (corresponding to λ_i) of A, of length T, and the a_i are orthonormal, that is $(a_i, a_j) = \delta_{ij}$; and (3) b_i is the ith eigenvector of B, of length R, and the b's are also orthonormal. The decomposition in (1′) exhibits Y as the sum (weighted by $\sqrt{\lambda_i}$) of K degenerate $R \times T$ matrices, each the product of an R-component column vector, post-multiplied by T-component row vector.

We find the largest eigenvalue λ_1 and its associated eigenvector a_1 by subjecting the $T \times T$ matrix A to an eigenvalue program. To avoid next computing and working with the larger $R \times R$ matrix B (perhaps 200 × 200 or 1,000 × 1,000), we postmultiply both sides of (1′) by a_1, obtaining

$$Ya_1 = \sum_{i=1}^{R} \sqrt{\lambda_i}\, b_i a_i' a_1 \tag{2'}$$

$$= \sum_{i=1}^{R} \sqrt{\lambda_i}\, b_i \delta_{i1} = \sqrt{\lambda_i}\, b_1.$$

From this expression we see that from a_1 we can compute b_1. The T-vector a_1 is the desired time pattern; that is, $a_1 = (\delta_1, \delta_2, \ldots, \delta_T)$ and $b_1\sqrt{R} = (\gamma_1, \gamma_2, \ldots, \gamma_R)$ is the desired set of row coefficients, normalized to satisfy $\sum \gamma_i^2 = R$.

Smoothed Scatterplot Analysis of Long-term Breeding Bird Census Data

by

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ABSTRACT.—Scatterplot smoothing using the LOWESS algorithm is proposed as a technique for summarizing population census data accumulated over a span of years. Scatterplot smoothing is compared with least-squares linear regression lines. As a descriptive method, it is superior to regression techniques because it does not excessively obscure detail and does not necessitate a priori assumptions about underlying processes. Unlike most procedures used to analyze time series, it does not require strictly periodic data sets. This procedure is used as the basis for ongoing studies of trends in populations of birds at several sites in the eastern and midwestern United States.

Introduction

Johnston (1990) identified 15 long-term data sets of breeding bird censuses taken at mature deciduous forest sites in the eastern and midwestern United States. Each data set consists of the density of pairs of land birds for each year a census was taken at a given site. Despite some possible limitations, the sets are potentially useful for comparative analyses of breeding bird population changes.

The data sets identified by Johnston display two properties which make their description and analysis problematic: (1) some sets are aperiodic, that is, census years are not evenly spaced over the duration of the study, and (2) in some sets, possible trends in the number of pairs over the years are obscured by a substantial amount of interyear fluctuation or "noise." Any procedures used to describe or analyze these data must deal with these properties. In this paper I present a method for the description of these unbalanced and variable data sets which will increase the likelihood of discovering trends or significant changes over time.

Methods

Standardization

To eliminate differences in scale, the reported numbers of breeding pairs for each year in each of the censuses were standardized to the number of pairs per 100 acres.

Grouping

The standardized number of pairs for each species listed in the data sets was totaled over all species and subtotaled into two mutually exclusive subcategories, neotropical migrant species, and short-distance migrant and resident species. Thus, for each data set, three series of standardized counts, total, neotropical, and resident, were produced.

Smoothing

Standard time series models are not applicable to these data sets because of their aperiodicity. For this reason, and to avoid imposing an a priori model on the data, scatterplot smoothing was used to examine them. Such smoothing techniques can be used to visualize trends otherwise obscured in data sets characterized by substantial, apparently random, fluctuations (noise) from one observation to the next.

The smoothing method selected for the breeding bird census data was Cleveland's robust locally weighted regression algorithm (LOWESS; Cleveland 1979), as implemented in SYSTAT, version 3.0 (Wilkinson 1987). This method produces curves that are relatively insensitive to the values of outlying data points. It allows, by adjustment of the value of a parameter, f, user-control over the degree of smoothing of the data – that is, the extent to which each smoothed point is influenced by adjacent points. A good description of this method is given in Chambers et al. (1983).

The procedure consists of the following steps:

1. For each point in the original data set, a line is fitted to it along with a fixed number of adjacent points contained in a strip on either side.
2. Neighborhood weights are assigned to all points in the strip, the selected point having the greatest weight. The weight function is symmetrical and decreases to zero with distance from the selected point.
3. A line is fit to the points within the strip, using weighted regression. The smoothed point lies on the fitted line at the same abscissa as the selected point.

Scatterplots

The standardized counts and smoothed values for each year of each census were entered into a SAS (version 5.16, SAS Institute, Cary, North Carolina) data set and plotted using SAS/GRAPH installed on a VAX 8800 minicomputer. The illustrations included in this report are taken directly from SAS/GRAPH output.

Linear Regression

Least-squares linear regression techniques applied to the standardized values were used to obtain straight lines.

Results

Standardized Data

The data set from the Rock Creek Park, D.C., site was used, as an example, to construct the plot of counts of total, neotropical, and resident pairs shown in Fig. 1. This plot reveals two features characteristic of many of the data sets: (1) aperiodicity, and (2) substantial fluctuation from one year to the next (noise), possibly obscuring underlying trends.

Smoothed Data

For the same site, smoothed neotropical, resident, and total counts are plotted in Figs. 2 and 3. In addition to illustrating scatterplot smoothing, these figures demonstrate the effect of the value of *f* (0.25 and 0.50) on the degree of smoothing obtained with LOWESS.

Linear Regression

Straight lines fitted to the standardized counts for the Rock Creek data are shown in Fig. 4.

Discussion

Several authors recently have recognized the importance of long-term population counts of birds to detect population trends. A variety of methods

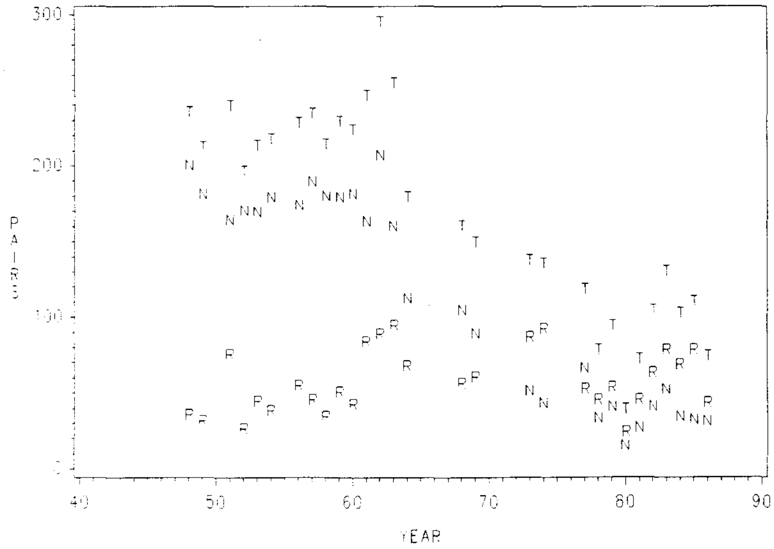

Fig. 1. Standardized counts of neotropical (*N*), resident (*R*), and total (*T*) pairs at Rock Creek Park, D.C. 1948–86.

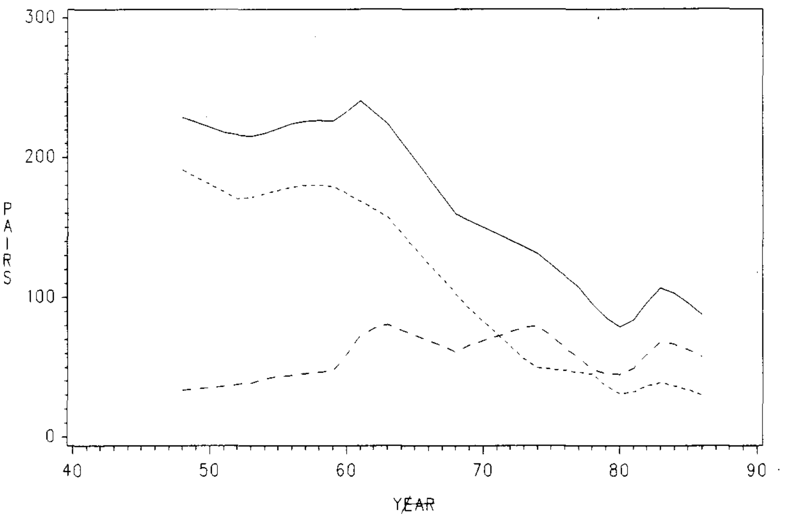

Fig. 2. Smoothed counts (*f*=.25) of neotropical (*dotted line*), resident (*dashed line*), and total pairs (*solid line*), Rock Creek Park, D.C., 1948–86.

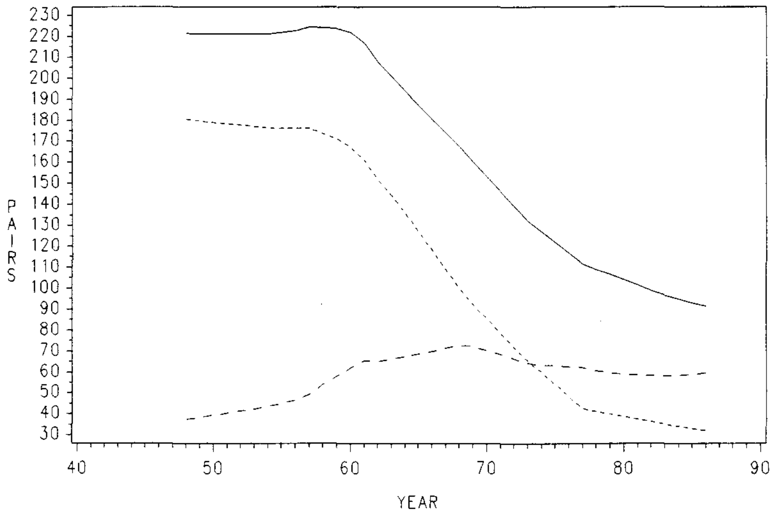

Fig. 3. Smoothed counts (*f*=.50) of neotropical (*dotted line*), resident (*dashed line*), and total pairs (*solid line*), Rock Creek Park, D.C., 1948–86.

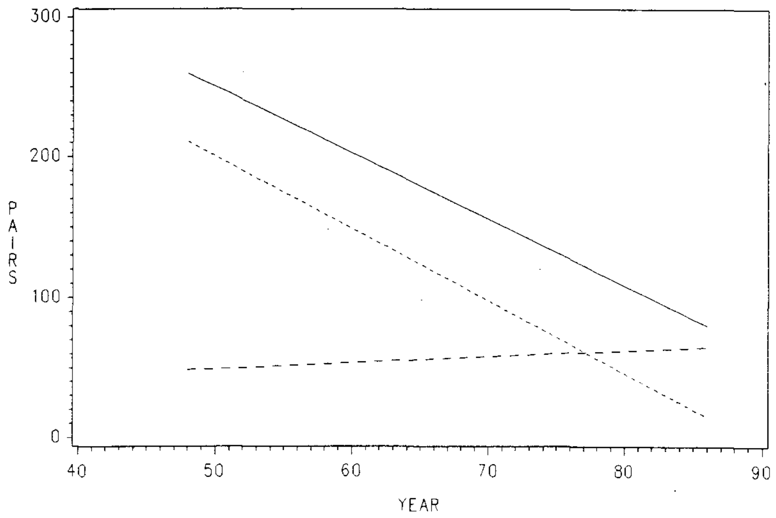

Fig. 4. Least-squares straight lines fitted to the standardized neotropical (*dotted line*), resident (*dashed line*), and total counts (*solid line*).

have been used to describe and interpret the resulting data. Wilcove (1988), for example, described population changes at 10 Great Smoky Mountain sites by comparing different censuses taken 34–35 years apart. Robbins et al. (1986) used linear regression of transformed annual roadside counts taken over a period of 15 years to investigate trends in bird populations distributed throughout the United States. Hall (1984a, 1984b), for long-term census data of Appalachian spruce forest bird populations, simply tabulated his counts or presented linear regression lines of the untransformed data. Holmes et al. (1986) also used simple linear regression to describe bird population changes. Their study spanned 16 consecutive years at the Hubbard Brook Experimental Forest in New Hampshire.

These reports, however, reveal some of the pitfalls inherent in deciding whether significant population changes (i.e., trends) have occurred over long time-periods. The Breeding Bird Survey data (Robbins et al. 1986), while extensive, are fit to log-linear regression models to discover trends. Although fitting data to a model is necessary for some statistical testing techniques, the required assumptions (e.g., linearity of the transformed counts) are not necessarily realistic and may obscure details such as whether any conjectured increase or decrease in population size began during or before the study period. Simple linear regression, such as applied by Hall, also requires the assumption that the rate of change in a population is constant over time.

Wilcove's study does not depend on graphical analysis and does not attempt to fit data to an a priori model. Instead, it compares different counts obtained 34–35 years apart. Wilcove used a nonparametric technique (chi-squared goodness of fit tests) to conclude that, at his sites, no significant population changes had occurred in neotropical migrants. Although this technique does not require that assumptions be made about any trends underlying the data, it is not as powerful as techniques available for the analysis of linear models and only considers two points in time at each site. It is, therefore, not as likely to reveal underlying trends.

The present paper does not address the issue of testing hypotheses about trends. Rather, it focuses on the problem of adequate description of the census data. By smoothing the breeding bird census data, one can easily visualize whether there have been population changes over time. The advantage of this presentation over simple linear regression is evident from comparison of Fig. 2 or 3 with Fig. 4. While linear regression obscures considerable detail, scatterplot smoothing appears to abstract underlying changes over time without excessive loss of detail.

The effect of the parameter *f* on the degree of smoothing is evident from visual comparison of Figs. 2 and 3. The greater the value of *f*, the greater the degree of smoothing and loss of detail. Unlike regression, however, scatterplot smoothing allows user-control over the degree of loss of detail.

An obvious advantage of least squares regression is that it permits testing of the regression coefficient, a measure of the rate of change over time, for statistical significance. If necessary for the purposes of statistical hypotheses testing, appropriate models can be fit to smoothed data sets. Should a smoothed scatterplot suggest, for example, a biphasic pattern (e.g., no changes during the earlier years at a site, but a population decline later), a piecewise linear regression model could be explored. Current efforts in this continuing study are exploring such models where appropriate, both for species grouped as described earlier and for individual species.

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Methodological Issues in the Estimation of Trends in Bird Populations with an Example: the Pine Warbler

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ABSTRACT.—The North American Breeding Bird Survey (BBS) is designed to provide estimates of the distribution of birds in North America and trends in their abundance. In the recent 15-year summary of BBS data by the U.S. Fish and Wildlife Service (Robbins et al. 1986), the data were analyzed by a linear, parametric method developed by Geissler and Noon (1981) and modified by Geissler (1984). This method, which we call linear route regression (LRR), gives the slope of an index to linear trends in overall population size on a log scale. In this paper we compare the LRR method of analysis with a method developed by Mountford for the analysis of censuses made by the spot-map method of censusing in England. The Mountford method measures yearly fluctuations in unsmoothed data, but not trends.

We also present here a new method, which we call nonlinear nonparametric route regression (NNRR). Nonparametric route regression is similar to LRR in the way it aggregates data from the route level to obtain estimates of trends for larger geographic regions. The major difference is that NNRR does not force the data into straight lines on a log scale. It uses LOWESS, a locally weighted scatterplot smoother to allow flexibility in the degree of smoothing of the data. Because data are fit directly on a route-by-route basis, NNRR does not require special weighting by abundance, the use of logarithms, or corrections for zero counts, and routes representing equal areas are weighted equally. Using NNRR, we can directly fit a measure of abundance: mean stops per route on which the species of interest was observed. We also explore the value of additional smoothing of the data.

We illustrate the new method with an analysis of BBS data for the pine warbler (*Dendroica pinus*) in the central southern and southeastern region of the United States. In this example we show that much information that would have been obscured by LRR can be displayed with NNRR. By defining a trend as log slope in LRR, one can obtain a single p-value for its significance, but, in this process, much other information about trends is lost.

Introduction

The North American Breeding Bird Survey (BBS) is the most ambitious attempt to monitor populations of animals in nature that has ever been conducted. Robbins et al. (1986) and Droege (1990) discuss some important difficulties that arise in the analysis of BBS data. Here we review the subjects of data quality, missing data, aggregation of data by routes into larger areas, weighting of data, and model choice. We compare the route regression method of Geissler and Noon (1981) and Geissler (1984), which was used in the 15-year summary of the BBS (Robbins et al. 1986) and which we refer to as linear route regression (LRR), with a method developed by Mountford (1982, 1985) for analysis of data from the Common Birds Census in England. Then we propose a new method, nonlinear nonparametric route regression (NNRR). The new method is based on first smoothing data for each route by locally weighted regression (LOWESS; Cleveland 1979, 1981; Chambers et al. 1983) and then aggregating the resulting values by physiographic strata within States. To illustrate the method, we analyze data for the pine warbler (*Dendroica pinus*) in the central-southern and southeastern regions of the United States for the 22-year period 1966–87. An outline of the recommended procedure is given in the Appendix.

Statistical Issues

Data Quality

Without high quality data, no statistical method will give reliable analyses. Because the BBS depends on volunteers, whose work can only be minimally supervised, data quality is an important consideration (Robbins et al. 1986; Droege 1990). "If a measurement procedure leads to biased estimates, taking a large sample doesn't help. It just repeats the basic mistake on a larger scale" (Freedman et al. 1978:303). Thus, care must be taken to improve and monitor the data quality, even if data quantity must be sacrificed.

Missing Data

A difficult aspect of the development of statistical methods for the BBS is that many routes have not been run every year. If there were an association between abundance and the pattern of missing data, then ignoring the missing data could lead to erroneous conclusions. For example, if there were more missing data in later years of a survey from the routes of higher abundance, then an increasing population trend would be underestimated or estimated to be negative when it was not. Consider the example given in Table 1. There is no population trend at any location. But, because there are more missing data at the sites of higher abundance, there seems to be a decline when only the averages are considered. A simple average of the routes with data present is misleading because it puts more weight on the routes with smaller abundances in the later years.

It is possible to use the data that are present to estimate the pattern for years for which data are missing. Both the route regression method and the Mountford method do so by fitting a model that incorporates route effects. In Table 1, if the missing data are first estimated within route and are then averaged, the results correctly show no trend.

Aggregation

Premature aggregation of routes on a geographic level will hide trends at the route level. It was premature aggregation of data across routes that led to the misleading decline in the averages in Table 1. The temporal aggregation of data also affects what trend is being estimated. Trends may be positive for one group of years and negative for another. An appropriate method of analysis should be sensitive to different trends for different sets of years.

Weighting

If the analysis involves aggregation of routes, the question of weighting needs to be addressed. The choices of whether to weight by area represented, abundance, and statistical precision, are difficult.

If the routes represent the areas in which they are located, as is the case with BBS data, then weighting by the area represented by each route is reasonable. On the other hand, with the Colonial Bird Survey, the data do not represent abundance in a surrounding area, and weighting by abundance would not be reasonable.

If trends in an overall population are desired, weighting by abundance should be performed. If a large population on one route is declining and a small population on another route is increasing, the overall trend is a decline. This situation is illustrated in Table 2, in which the route with the large population shows a halving in population size each year and the route with the small population shows a doubling. Route averages are automatically weighted by abundance, so they show the overall decline, but the overall average proportional change is unweighted, and it shows a misleading increase.

There are situations in which abundance weighting should not be used. For example, if the proportion of routes that are declining is the information sought, abundance weighting would not be appropriate.

Table 1. An association between missing data and abundance can falsely indicate a population decline when only the averages are considered.

	Year				
Route	1	2	3	4	5
1	32	32	–	–	–
2	20	20	20	–	–
3	14	14	14	14	–
4	2	2	2	2	2
Average	17	17	12	8	2

Weighting by statistical precision should always be used, but the development of a proper method needs further study. The LRR method weights by components of the within-route estimated variance, but this is not a good idea. Observations within a route among years must be correlated, and the amount of dependence within routes should be considered in the development of a weighting scheme.

Choice of a Model

The model that is fit to the data determines how the trends are estimated, and it also determines the smoothness of the estimates. If the model requires that the trend be a smooth function, then the trend will be smooth. If there is flexibility in the model, the trend may be irregular. The efficiency of the estimates will be a function of the type of model used. A fully efficient method should be sensitive to the correlation structure of the data.

Comparison of the Route Regression and Mountford Models

In this section, we compare the LRR method of Geissler (1985) and the method of Mountford (1982, 1985) with respect to missing data, aggregation, and weighting.

Both methods have suitable ways for handling missing data. With LRR, which analyzes the data on a log scale, a separate regression line is fit for each route, so each line has its own slope and intercept. The estimated slopes are then combined by means of a weighted average. This method avoids the problem of having no weight for years in which data are missing (Table 1). In a somewhat similar fashion, Mountford's method has site effects that correct for missing data.

With LRR, the results of route-by-route analyses are aggregated to larger geographic levels. The entire set of years is used to find a single estimate of a trend. Of course, a subset of the years could be selected to search for trends over shorter periods. The Mountford method does not use either geographic or temporal aggregation. Separate effects are estimated for each year. In fact, the Mountford method measures yearly fluctuations, not trends. Geissler (1985) and Sauer and Geissler (1990) have suggested a supplement to LRR in which yearly fluctuations are estimated by analysis of residuals.

Linear route regression uses weights equal to the product of the area, the abundance, and a component of the inverse of the variance of the slope estimate (the diagonal element of $(X'X)^{-1}$, where X represents the model matrix for the within-route regression). As mentioned above, we think that weighting by the inverse of the variance of the slope estimate, or components of it, is not optimal. There is substantial route-to-route variation in the BBS data, so it would not be wise to allow a route with a good within-route fit to greatly overshadow the other routes. A better weighting scheme would weight by a combination of within-route and between-route variabilities. The Mountford method

Table 2. Example demonstrating that an overall decline in a population can be adequately illustrated by averages but that it would be masked if unweighted estimates of the trend were calculated.

	Year				Trend (annual
Route	1	2	3	4	proportional change)
1	192	96	48	24	0.50
2	2	4	8	16	2.00
Average	97	50	28	20	1.25

does not use any type of weighting, but it could be adapted to use weighting schemes.

In many ways, the models fit by LRR and the Mountford analysis are similar. The LRR model is a linear regression through time on a log scale. The Mountford model is also multiplicative. More precisely, if we let C_{yr} denote the count for year y and route r, then the LRR model, ignoring observer effects, is given by

$$\log(C_{yr} + .5) = \log(a_r) + y * \log(b_r) + \text{error}, \quad (1)$$

and the Mountford model is given by

$$C_{yr} = a_r * b_y + \text{error} \quad (2)$$

From this equation, we see that the Mountford analysis uses an additive error on the original scale, whereas the LRR analysis uses an additive error on the log scale. If we consider only the mean values and ignore the constant of .5 that is added to correct for zero counts, then the models can be written as

$$\log(C_{yr}) = \log(a_r) + y * \log(b_r) \quad (3)$$

for LRR, and

$$\log(C_{yr}) = \log(a_r) + \log(b_y) \quad (4)$$

for the Mountford analysis. From these equations, we can see that both methods fit additive models on the log scale, with separate constants for each route. They are different, however, in that LRR fits separate slopes for each route but assumes a constant trend across years, whereas the Mountford method fits separate effects for each year but assumes that they are common to all routes. The LRR analysis summarizes the information by estimating the linear trend on the log scale for the entire period considered in the analysis. It produces as smooth a trend estimate as is possible. The Mountford method is at the other extreme, fitting each year with a separate effect, allowing the ultimate in flexibility. It will tend to yield irregular estimates of a trend through time.

The LRR and Mountford analyses handle variances and covariances in the data in extremely different manners. The LRR method ignores correlation within a route when fitting separate slope estimates. It uses between-route variability to estimate standard errors of the trend estimates. Because the trends are estimated directly, confidence intervals on the mean abundance cannot be calculated. For this reason, the diagrams in Robbins et al. (1986) that give confidence intervals are for the trend estimates only. They should not be interpreted as confidence bands for the mean abundance line as a function of time. The Mountford method estimates the correlations in the yearly ratio estimates to obtain slightly more efficient estimators. Either method is suitable for the accommodation of the correlations in the data and the calculation of standard errors.

How might these methods be improved? They both handle missing data suitably, and the LRR addresses aggregation well by building from a route-level analysis to larger geographic regions. We suggest improvements in the other two areas: weighting and model to be fit. If the numerical data are fit directly on a route-by-route basis, then no abundance weighting need be done. Fitting the data directly also avoids the complications involved with logarithms and the corrections needed for zero counts. If the major component of variation is route-to-route variation, then routes representing equal areas should be weighted approximately equally, and the within-route variation should essentially be ignored. Though still not optimal, this is the weighting we have chosen. With respect to the model to be fit, we suggest one that is intermediate between the ones used with LRR and with Mountford's method. Mountford's method does not use any of the information from year to year to try to remove extraneous variation that is not part of a trend. On the other hand, the LRR produces only a single estimate for the entire period considered and hence does not help to discover trends over shorter periods. We suggest the use of a method that allows the estimates to be smoothed somewhat but not forced to be straight lines on the log scale.

Because each route is conducted only once each year, some of the between-year variation is undoubtedly attributable to factors other than long-term trends in the bird population. Trends should be more evident if some of this extraneous variation is removed by smoothing. We use LOWESS (locally weighted scatterplot smoother; Cleveland 1979, 1981; Chambers et al. 1983) for two reasons. First, it allows us to judge trends without having to select in advance the years for which the trend is to be calculated. For example, a trend that began in the middle of the 15-year period of the Robbins et al. (1986) analysis would be more sensitively detected by our method than by a linear trend analysis. Second, it is a conditional smoother; that is, it entails no assumption that the values on the x-axis (years) are equally spaced.

The degree of smoothing with LOWESS is optional. If f, the smoothing parameter, is set to 1.0, the smoothing is complete, and the result is nearly a straight line. If f is set to 0.5, half of the data are scanned to calculate each fitted value, and very general patterns can be expressed. In Fig. 1, a single route (No. 7007) from the BBS scissor-tailed flycatcher (*Tyrannus forficatus*) data is fit with LOWESS. Small values of f (near zero) allow many changes in the fitted line; large values of f (near 1) lead to nearly linear fitted lines. Table 3 gives hypothetical data and shows how variances and confidence intervals can be calculated for LOWESS lines using route-to-route variability. The data consist of six routes in one stratum-within-State and seven routes in the other stratum-within-State. The first stratum-within-State is assumed to be 100 units in area, and the other is assumed to be 50 units. Because these calculations are simply weighted averages, there is no need for bootstrapping.

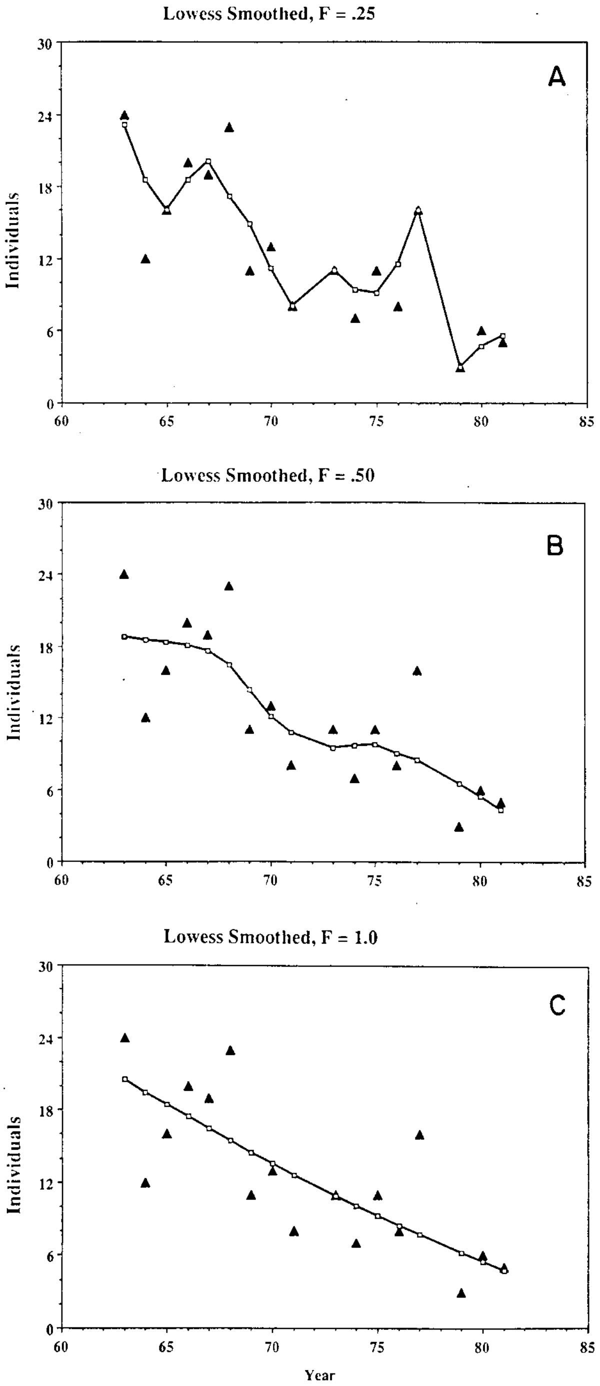

Fig. 1. Population trend for the scissor-tailed flycatcher (*Tyrannus forficatus*) on one route (No. 7007) showing successively more smoothing in *A*, *B*, and *C* using LOWESS.

Example of the Proposed Method: the Pine Warbler

To explore the usefulness of the proposed method for the examination of trends in a particular bird population, we present an analysis of data for the pine warbler, a common breeding bird of pine woods from southern Canada to the Gulf of Mexico. We consider only the nine-State area of the central-southern and southeastern United States (Fig. 2, Table 4).

Data Quality, Missing Data, Aggregation

The BBS data for each route in each year have been rated by the staff of the Fish and Wildlife Service on the basis of weather and the reliability of observers. We have used only type 1 data, the type they judged to be most reliable. For the 22-year period 1966–87, there were 399 routes in the region for which there is some type 1 data. However, many routes were not run in all 22 years, and the data for some routes were judged to be less reliable for certain years. For the 399 routes on 22 years, about 54% of the total possible records are available. Our criterion for inclusion of a route with missing data was that at least 10 years be represented and that there be at least 1 year of data in each of four periods: the first 6 years, each of the next 5-year periods, and the last 6 years. The 201 routes that met these criteria were deemed sufficiently complete to be included in our analysis (Fig. 2). Note that the selection of routes was not affected by the presence of pine warblers but only by the reliability of the survey and the coverage of the period of interest.

Because of insufficient data, we were not able to include Louisiana or South Carolina in our analysis. In each of these States, there were long series of years in which no surveys were conducted. Also, we excluded stratum-State units for which there were fewer than three routes (stratum 1 in Florida, strata 3 and 13 in Georgia, and stratum 4 in North Carolina).

We have not addressed the issue of estimation of missing values. (In one case, estimation of the State line for Georgia for 1969 and 1970, we used an average to get a missing value.) By setting a criterion for the estimation of missing values, one could use more of the data. Whether or not this procedure would change the result would have to be determined.

Choice of an Abundance Criterion: Stops per Route

There are two logical choices for a criterion of abundance for Breeding Bird Survey data: the total number of individuals of the species recorded on the 50 stops of one survey and the number of stops out of the

Table 3. Calculation of mean and variance in LOWESS estimated values by route into stratum-within-State units and aggregation of these values to get average State values and their variances, without smoothing above the route level.

		LOWESS values by year (stops per route)				
Stratum-within-State	Route	1	2	3	4	5
Unit 1, Area = 100	1	0	0	0	1	1
	2	1	3	4	5	6
	3	2	4	6	7	7
	4	1	1	1	1	1
	5	2	3	4	2	2
	6	4	5	4	4	4
Stratum-within-State, 1, mean		1.67	2.67	3.17	3.33	3.50
Estimated variance of mean (s^2/n)		0.31	0.58	0.83	0.98	1.12
Unit 2, Area = 50	1	1	3	4	5	1
	2	2	4	4	4	3
	3	5	5	4	4	3
	4	6	6	7	6	6
	5	1	2	0	1	2
	6	1	1	1	1	1
	7	3	3	5	3	3
Stratum-within-State, 2, mean		2.71	3.43	3.57	3.43	2.71
Estimated variance of mean (s^2/n)		0.71	0.49	0.94	0.60	0.48

Means, variances, and confidence intervals

Weighted average = $\Sigma w_i L_i = (100L_1 + 50L_2)/150$

Variance = $\Sigma w_i^2 s_i^2 = (100/150)^2 (s_1^2/n_1) + (50/150)^2 \left(s_2^2/n_2\right)$

	1	2	3	4	5
State weighted average	2.02	2.92	3.30	2.37	3.24
Variance of weighted average	0.21	0.30	0.46	0.49	0.54
For approximate confidence intervals, use ± 2 $\sqrt{\text{var}}$.	0.92	1.10	1.36	1.40	2.08

total of 50 at which the species was recorded. Robbins et al. (1986) used the former; Cox (1987) used the latter. Of course the variable of most interest is the number of birds present, but there are several reasons why stops per route might be a more reliable indicator of abundance than the actual count of individual birds. First, it is less difficult for an observer to determine whether or not a species is present at a particular stop than it is to determine how many individuals of each species are present. Second, there is probably a greater difference between observers in judging the number of individual birds than there is in determination of whether the species is present (Bart and Schoultz 1984; S. Droege, personal communication). Also, analysis by stops per route would be simpler than analysis by individuals. For these reasons, a high positive correlation between these two criteria would be justification for using stops per route on which the species was recorded as a measure of abundance.

We examined data for 18 routes in the Lower Coastal Plain (stratum 3) in northern Florida. Data for all 18 routes were pooled, and average stops per route on which pine warblers were recorded was plotted along with the average number of individual pine warblers that were seen or heard per route (Fig. 3). The two variables are highly correlated. When their standard deviations by year are compared, the variation around these average values is less for stops per route. All these factors supported our decision to use stops per route as our abundance criterion.

Model to Fit: the Choice of a Smoother

A plot of the original data values and the smoothed LOWESS line with $f = 0.5$ for three routes in the Upper Coastal Plain stratum (stratum 4) in southern Arkansas illustrates the value of some smoothing. The trends are clear in the original data, but they are emphasized in the LOWESS lines (Fig. 4a). Smoothed lines for all nine routes in this stratum in Arkansas allow visual comparison of substantially more data, and a second smoothing of averages of all of these values expresses the general trend for the stratum-within-State unit (Fig. 4b). A comparison of

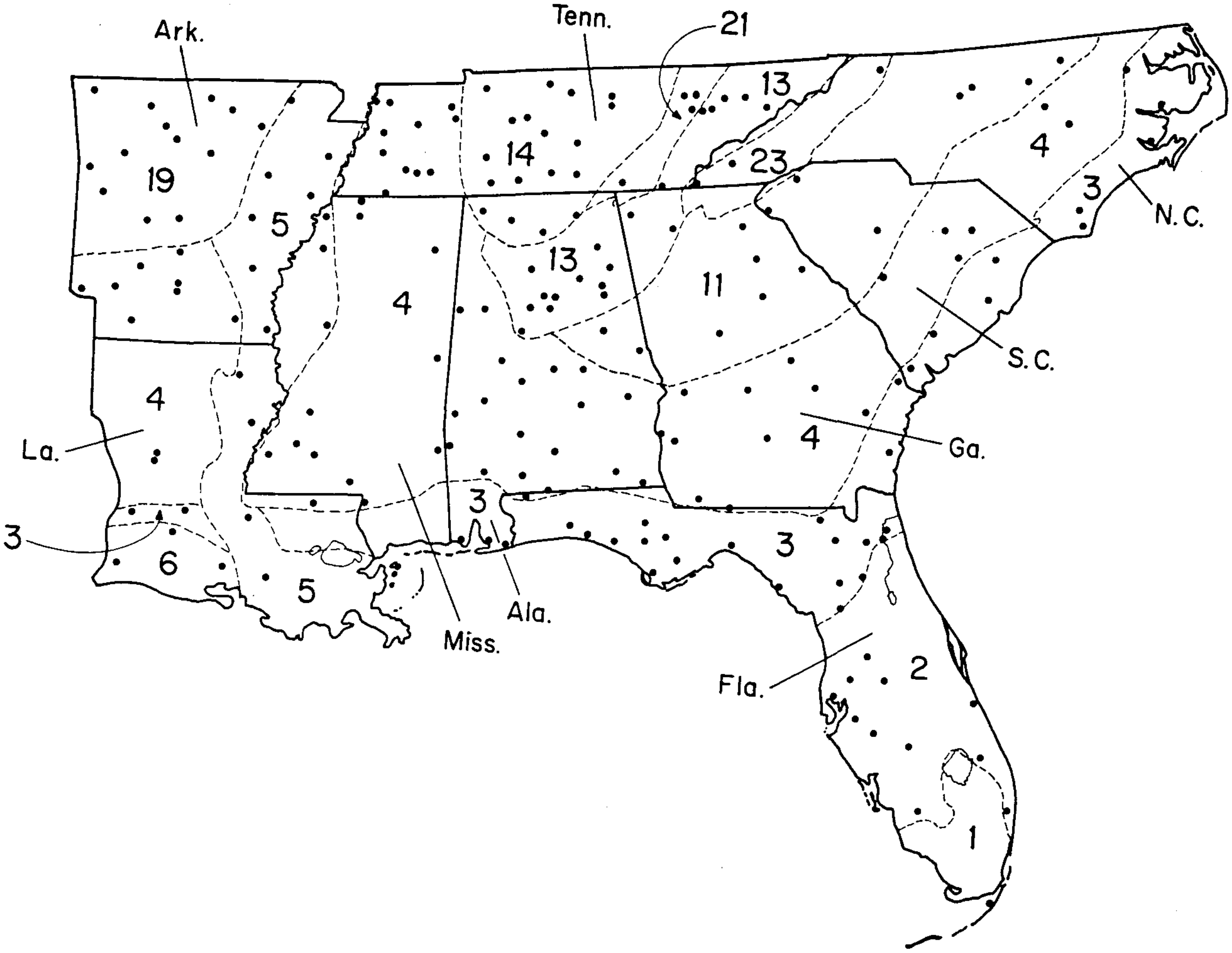

Fig. 2. The central-southern and southeastern region of the United States, showing the locations of 201 Breeding Bird Survey routes for which there are reliable data for a reasonable span of the period 1966–87 (see text). The physiographic strata (Robbins et al. 1986) are shown by *dotted lines* and are identified in Table 4.

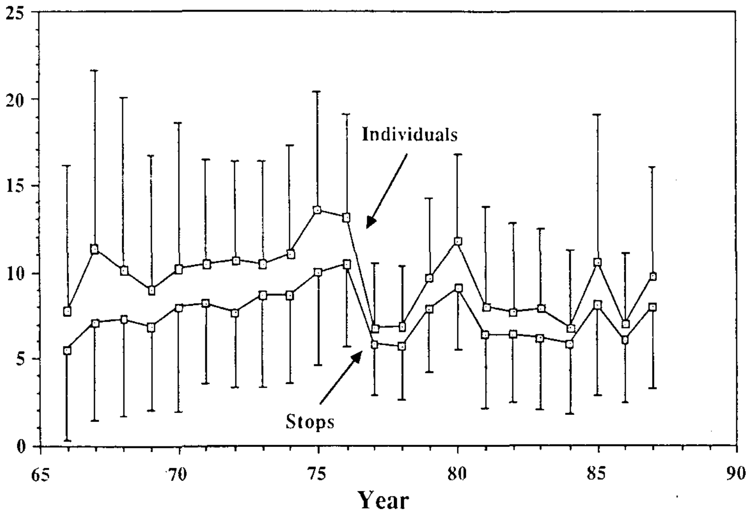

Fig. 3. The average number of stops per 50-stop route on which the pine warbler was recorded, and its standard deviation, plotted along with the average total number of individual pine warblers (*Dendroica pinus*) seen or heard and its standard deviation. The data are mean values for 18 routes in stratum 3 (Lower Coastal Plain) in Florida.

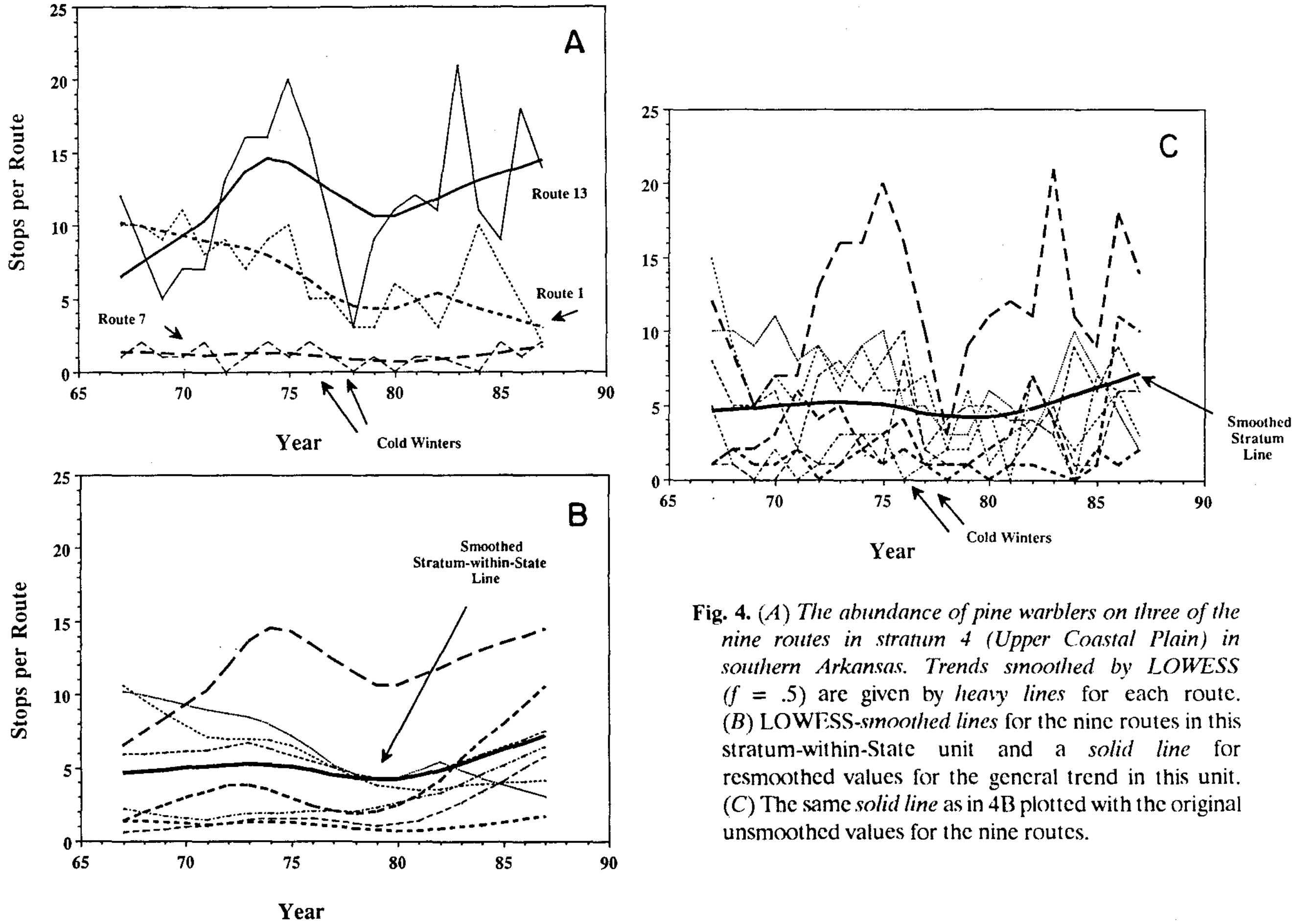

Fig. 4. (*A*) *The abundance of pine warblers on three of the nine routes in stratum 4 (Upper Coastal Plain) in southern Arkansas. Trends smoothed by LOWESS* (*f* = .5) are given by *heavy lines* for each route. (*B*) LOWESS-*smoothed lines* for the nine routes in this stratum-within-State unit and a *solid line* for resmoothed values for the general trend in this unit. (*C*) The same *solid line* as in 4B plotted with the original unsmoothed values for the nine routes.

this last line with the original values shows that the generally increasing S-shaped trend is very difficult to see in the morass of the original lines (Fig. 4c). Note, also, that the low values for the summer of 1978, which followed two extremely cold winters, have been obscured by the doubly smoothed stratum-within-State line. This example demonstrates the importance of selecting the degree of smoothing on the basis of the generality of the particular question of interest. If the question is to find the effects of particular events on bird populations, smoothing may be unwise. Expression of the data at more than one level of smoothing can be very helpful, but even mild smoothing can shift the time of the apparent occurrence of a change in the size of a population.

Aggregation and Smoothing

Because it is important to minimize bias attributable to differences among observers and to other site effects, we analyzed records for each route separately. Then, as in the LRR method, we averaged route values into units that are first physiographic strata within States. We obtained State or stratum values by averaging stratum-within-State values and weighting by proportional areas. A stratum that has a strong increase in pine warblers will not greatly affect a State trend if that stratum occupies only a small area within the State. See for example stratum 4 in Florida (Table 4; Fig. 5d). We constructed State and regional trend lines using weighting proportional to area (Table 4) as suggested by Geissler and Noon (1981), but we have not weighted the data by precision as they suggest. Finally, we obtained regional values by averaging State or stratum values and again weighting by proportional area. With this aggregative method, trends at various spatial scales can be compared graphically. In each State there are three to six stratum-within-State units (Table 4; Fig. 2).

Trend lines are affected by both the level of smoothing and whether smoothing is applied at various levels of aggregation. If data are smoothed at the route level and then aggregated by calculation of means to get trends for stratum-within-State units and State trends, each weighted by proportional area, the trends are somewhat less clear than they are if the smoothed values

Table 4. The proportion of the area of each physiographic stratum in each State, the proportion of each State in the central southern region, and the number of routes with reasonably complete and reliable data by State.

	AL	AR	FL	GA	LA	MS	NC	SC	TN	Total
Area (km^2/1,000)	81.0	83.8	87.2	116.2	72.5	76.3	78.7	47.8	66.7	710.2
Proportion of region	0.114	0.118	0.123	0.164	0.102	0.107	0.111	0.067	0.094	1.00
No. of complete routes	37	28	32	18	12	14	11	10	39	201
No. of strata	5	3	4	5	4	3	4	3	6	37
Proportions of strata within States[a]										
1 Subtropical			0.130							
2 Floridian			0.454							
3 Lower Coastal Plain	0.028		0.327	0.113	0.112	0.037	0.264	0.267		
4 Upper Coastal Plain	0.560	0.238	0.088	0.378	0.340	0.787	0.199	0.372	0.212	
5 Mississippi Alluvial Plain		0.289			0.304	0.177			0.024	
6 East Texas Prairies					0.245					
11 Southern Piedmont	0.078			0.239			0.365	0.360		
13 Ridge and Valley	0.269			0.239					0.183	
14 Highland Rim	0.066								0.409	
19 Ozark Ouachita Plateau		0.473								
21 Cumberland Plateau									0.111	
23 Blue Ridge Mountains				0.030			0.172		0.061	

[a] States are numbered as in Robbins et al. 1986, Fig 1.

by route are smoothed again at the higher levels. For Arkansas, Florida, and North Carolina, the successively smoothed lines are given in Figs. 5b, d, and f, and the lines based on only initial smoothing by routes and then aggregation by weighted means are given in Figs. 5a, c, and e. In each case the State line is the solid line.

A trend line for the region can be constructed from values for States (Fig. 5), if they are weighted by the proportion of the region occupied by each State. Again, the sensitivity of the trend to variation will depend on the amount of smoothing. If smoothing is applied only to the route data and means are used to aggregate successively larger areas, the regional trend (Fig. 6a) can show the effects of individual years. Note, for instance, the decline in 1981 in Alabama, Georgia, and North Carolina, an effect that is particularly evident in the Southern Piedmont (stratum 11) of North Carolina. To discover whether this is a coincidence or a real decline would take further work. Such phenomena are not apparent when the data are smoothed at each stage of the aggregation (Fig. 6b), but such a plot gives a nearly linear regional trend against a background of less smoothed State lines. The generality of the trend is accentuated at larger spatial scales. The analysis is based on data that seemed hopelessly heterogeneous at the beginning but has been reorganized and simplified. All States show increasing populations of pine warblers. It would be possible to place standard error bars on the NNRR curves to show the variability associated with individual year estimates. However, the NNRR method is not designed to give estimates of standard errors for a single, overall trend measurement, such as the linear trend on the log scale. The strength of the NNRR method is its ability to indicate shorter term trends that might be obscured by an overall measure.

In Fig. 6d, it is clear that in the region the pine warbler has been especially abundant in the Lower Coastal Plain (stratum 3) throughout the 22-year period. Note that the physiographic region in which the population has shown the greatest increase is the Southern Piedmont (stratum 11, mainly the Carolinas and Georgia). These increases plus increases in the Upper Coastal Plain (stratum 4) account for most of the large increase in the population as a whole (Fig. 6d). In Alabama, Arkansas, Florida, and Mississippi, there were slight declines in the late 1970's and early 1980's.

A widespread decline in the number of pine warblers occurred after the severe winters of 1976–77 and 1977–78 (see Fig. 3 for northern Florida, Fig. 4c for southwestern Arkansas, Fig. 6a for the entire region). Another apparent decline occurred in 1981 in North Carolina, Georgia, and Alabama (Fig. 6a), especially in the Southern Piedmont stratum (Figs. 6c, d, and Fig. 7). This decline is associated with a drought that began in May 1980 and continued through an exceptionally cold winter and into the very hot summer of 1981. Were normal numbers of pine warblers present but just not singing on these very hot, dry June days? The numbers returned to normal values in 1982, and general increases have continued through the 1980's. Increases in the

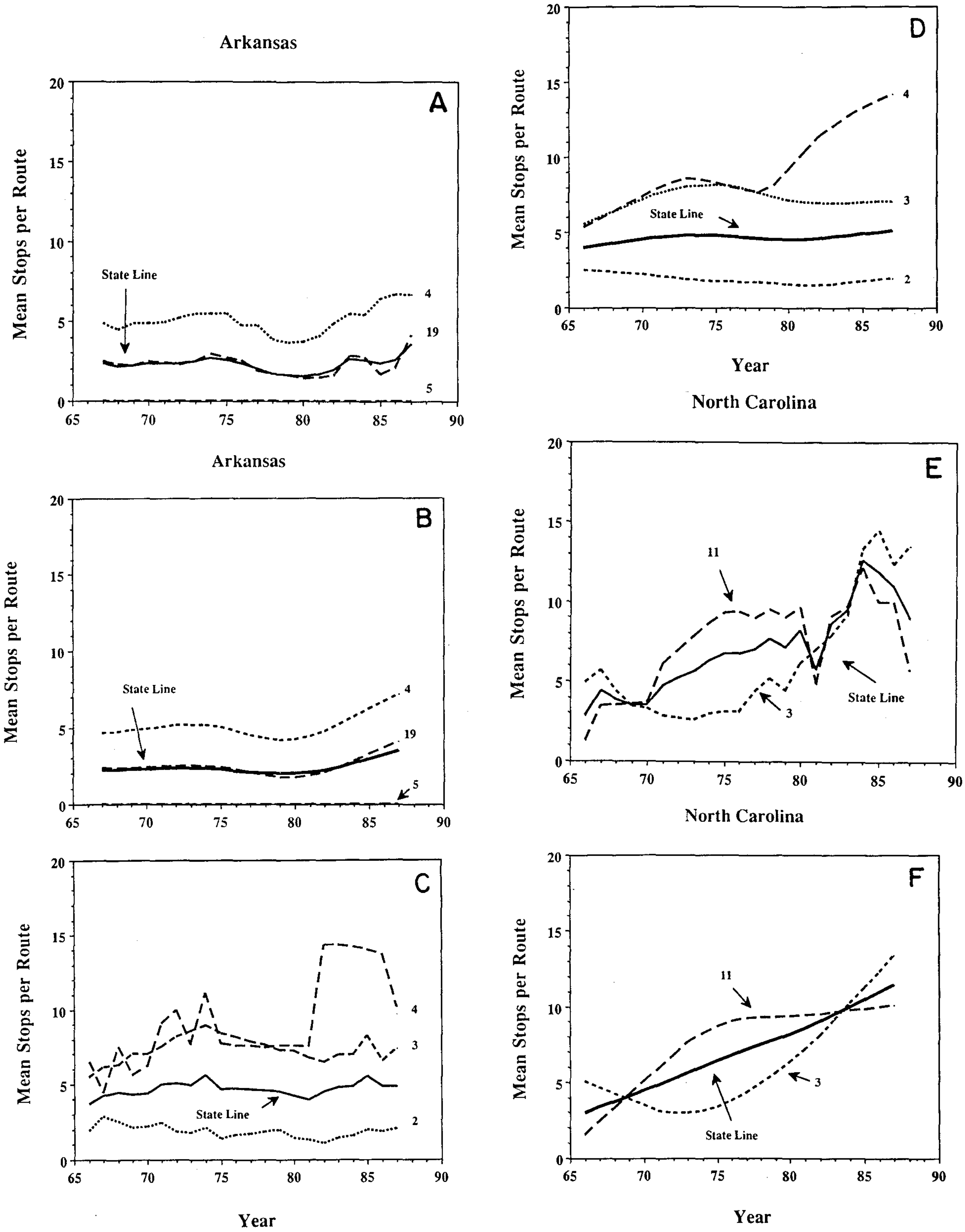

Fig. 5. Stratum-within-State pine warbler (*Dendroica pinus*) trends (*dashed lines; number indicates stratum*) and State trends (*solid lines*) for Arkansas, Florida, and North Carolina. Lines in A, C, and E were smoothed only at the route level. Lines in B, D, and F were smoothed at the route, stratum-within-State, and State levels.

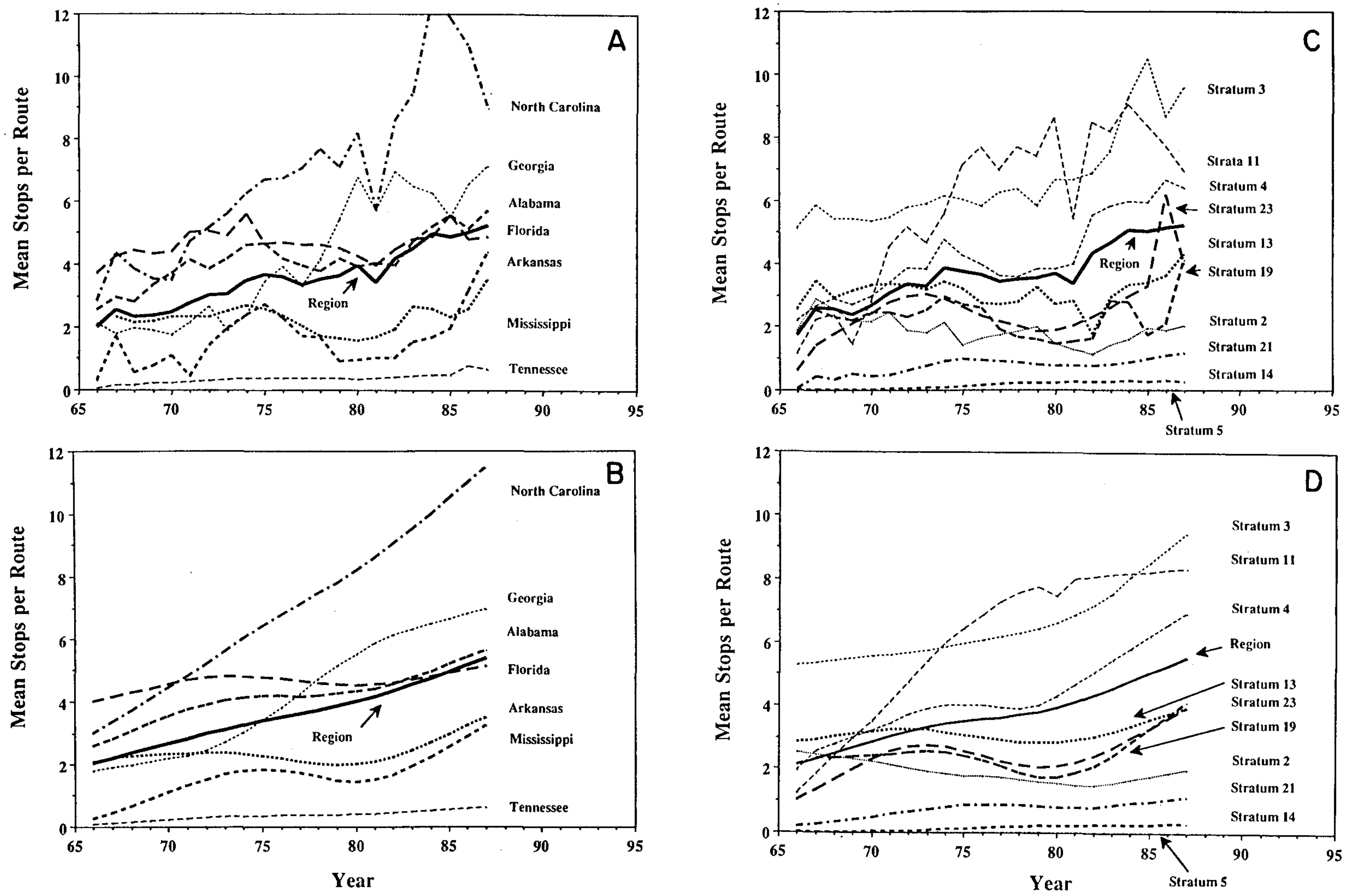

Fig. 6. State, stratum, and pine warbler (*Dendroica pinus*) regional trends: (*A*) State lines smoothed only at the route level. (*B*) Smoothing applied at the route stratum-within-State, State, and regional levels. (*C*) Stratum lines smoothed only at the route level. (*D*) Smoothing applied at the route, stratum-within-State, stratum, and regional levels.

abundance of pine warblers are exceptionally large in the Lower Coastal Plain and in the Southern Piedmont where timber management is heaviest. In the period of this analysis the overall acreage in managed pine in the southeastern States has declined, but much of what remains has matured into suitable habitat for the pine warbler. The highest density of breeding pairs recorded on a Breeding Bird Census in the southeastern coastal States was 30 pairs per 40 ha in managed loblolly pine (*Pinus taeda*) and shortleaf pine (*P. echinata*) pole timber (Hamel et al. 1982).

The pine warbler is a member of the genus *Dendroica*. Its congeners are mostly neotropical migrants. The genus is of particular concern because census data taken independently of the BBS suggested that populations of the neotropical migrants are declining (Hall 1984). Published analyses of BBS data have not shown declines for this group (Robbins et al. 1986; Cox 1987). Biologists and conservationists should give serious attention to why there is a disparity between the results of different types of data. We selected the pine warbler for study with the idea that future comparisons with its congeners should be instructive.

Summary

The analysis of BBS data requires serious attention to matters such as data quality, missing data, aggregation of data by routes, and weighting of data. In this paper we compared the linear route regression (LRR) method of Geissler with the method of Mountford. We proposed a new method called nonlinear nonparametric route regression (NNRR), which does not weight routes by components of the inverse of their variances and which does not require that trends be linear on a log scale, as does linear route regression. The new method was illustrated with data for the pine warbler. The advantage of NNRR is that there is no prejudgement of what a trend must look like, other than the selection of the smoothing parameter. With LRR, one can obtain a single P-value for the significance of a trend, defined as log slope, but much information is obscured.

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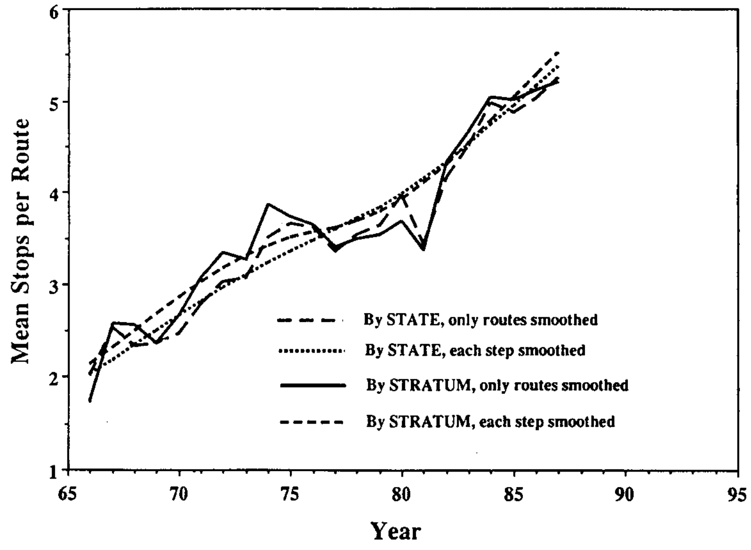

Fig. 7. Trend in the population of the pine warbler (*Dendroica pinus*) in the central-southern United States for 22 years, 1966–87, estimated by either State or stratum with two levels of smoothing.

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Appendix: Data Smoothing Procedure

Analyses were done on an Apple Macintosh computer with the following software:

Systat v3.1 (Systat, Inc., Evanston, Ill.) for LOWESS smoothing and some data selection;

StatView 512+ (BrainPower Software, Calabasas, Calif.) for data importing;

Cricket Graph (Cricket Software, Malvern, Pa.) for plotting; and

Absoft FORTRAN (Absoft Corp., Auburn Hills, Mich.) for writing utility programs.

1. Determine which routes are eligible for inclusion in the analysis. Criteria are:
   a. Type 1 data for at least 10 years out of the 22-year period;
   b. Type 1 data for at least 1 year in each 5–6-year period. The periods are:
      1966–71 (6 years),
      1972–76 (5 years),
      1977–81 (5 years),
      1982–87 (6 years).
2. At this time, Systat does not do LOWESS smoothing on a "BY" variable (as in "by route"), so a separate file must be made for each route. LOWESS is run on each file. The column with the smoothed data is then merged back into the original route file to have access to the column of year values. These merged route files are then converted to text format.
3. A utility program (AVGIT) is run on the smoothed route lines to get stratum-within-State averages. The program asks how many and which route files are to be input. A new file is created that contains averages of all smoothed route values of 1966, then for 1967,..., 1987. The program is run for each stratum-within-State in the region.
4. The stratum-within-State files (now with one value for each year) are read into Systat. If additional smoothing is desired, LOWESS is run on each file. They are saved in text format.
5. A utility program (MULTIT) reads all the smoothed stratum-within-State files in a particular State. The program then asks for the proportion each stratum is of the entire State area. A weighted average for each year is then calculated for the State. The program is run for each State in the region.
6. The State files are read into Systat. If additional smoothing is desired, LOWESS is run on each one. These are the final smoothed State lines. These are saved in text format.
7. A utility program (SMULTIT) reads all the smoothed State files and asks for the proportion each is of the entire region. A weighted average for each year is calculated for the region.
8. If additional smoothing is desired, the region line is read into Systat and LOWESS is run on it. This is the final smoothed region line.
9. Similarly, steps 5 through 8 can be used to aggregate by strata instead of by States.

Using Checklist Records to Reveal Trends in Bird Populations

by

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ABSTRACT.—Yearly population indices from the Wisconsin Checklist Project were compared to indices from the North American Breeding Bird Survey, the Christmas Bird Count, and migration counts from the Cedar Grove Ornithological Station. Checklist results were generally concordant with results of other surveys, and they provide an efficient method of monitoring population trends.

Introduction

When there are doubts about the validity of trends in bird population indices, one of the more convincing reassurances that the trends are real is a demonstration of concordance among several independent indices. Thus, parallel trends in several separate populations that have been studied independently or parallel trends derived from studying the same population in different ways become important corroborating lines of evidence. In this paper, we seek such corroboration by looking for concordance among population indices derived from four independent survey methods. Through these comparisons, we hope to validate the use of qualitative checklist records for detecting population trends and to provide an additional independent source of data on trends in Wisconsin bird populations.

Methods

Our approach is to summarize yearly population indices (1982–87) derived from four sources: the Wisconsin Checklist Project (WCP), the Breeding Bird Surveys (BBS), the Christmas Bird Counts (CBC), and migration counts from the Cedar Grove Ornithological Station (CGOS). We then compare the population trends suggested by these indices, looking specifically for patterns of concordance that indicate that the WCP is tracking the same changes in abundance as the other population monitoring schemes. Because the WCP data span the entire year, it is possible to compare them with the seasonal data from BBS, CBC, and CGOS.

Breeding Bird Surveys

We tabulated the average number of individuals detected per BBS route each year from 1983 through 1987 for 143 species of birds that were recorded in all 5 years and that were also included in the WCP. We also noted the names of the BBS cooperators who conducted counts each year and the date on which they made their counts. When analyzing the WCP data, we subsequently ignored the WCP records that these cooperators had submitted during the week of their BBS count. This insured that data from the BBS and WCP were independent with respect to observers.

Christmas Bird Counts

For all of the CBC's in Wisconsin from 1982 through 1986 (Hilsenhoff 1983, 1984, 1985, 1986, 1987), we tabulated the total number of individuals of each of 53 bird species detected per 1,000 party-hours each year. We also noted the dates on which CBC's in each county had taken place so that in subsequent analyses we could ignore WCP records from that county and week. This insured that data from WCP were independent of the CBC data.

Cedar Grove Ornithological Station

Each fall, from late August through late November, observers tally the number of migrating raptors that pass by the Cedar Grove Ornithological Station on the shore of Lake Michigan (Mueller and Berger 1967). We tabulated the total number of individual peregrine falcons and goshawks seen each year from 1983 to 1987 (G. Allez, personal communication). None of the observers at CGOS were participants in the WCP, so data were independent.

Wisconsin Checklist Project

For each year (1982 to 1987) we tabulated reporting frequencies (Temple and Cary 1987a) for various bird species over time periods and geographic areas that were appropriate for comparisons. We compared the mean number of individuals of each species per BBS route with the WCP reporting frequencies for each species during June in each year. We compared the number of individuals per 1,000 CBC party-hours with the WCP reporting frequencies for each species during December and January 1982–83 through 1987–88. We compared the annual tallies of raptors seen at CGOS with the WCP reporting frequencies for these species during September–November each year for all counties bordering Lake Michigan.

Comparative Methods

To detect concordance between the indices from the WCP and those of the BBS, CBC, and CGOS, we calculated correlation coefficients (*r*) for appropriate pairs of indices. We took a positive correlation to indicate concordance and a negative correlation to indicate lack of concordance. Correlation coefficients close to zero (i.e., 0.1) were somewhat ambiguous and occurred primarily when one or both of the indices being compared had not varied over the years being examined. In certain cases we also calculated regression coefficients that indicated the trends of the various population indices over the 5 years of the study.

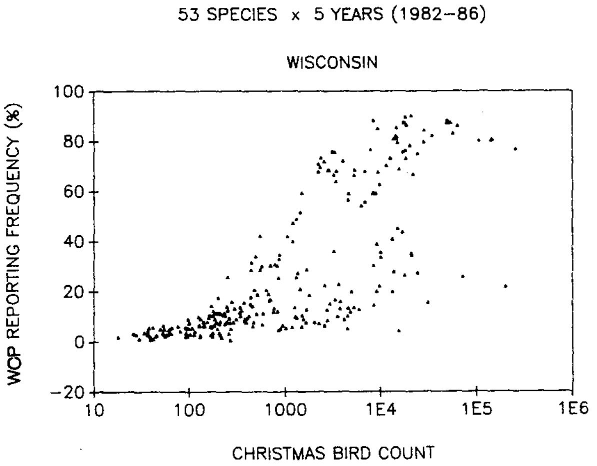


Fig. 1. The relation between WCP reporting frequencies and birds per 1,000 CBC party-hours for 53 species over 5 years (1982–86) in Wisconsin.

Results

Relation Between WCP and CBC Indices

In all, we calculated 265 indices of annual winter bird abundance in Wisconsin (i.e., 53 species × 5 years), both for the CBC and WCP. The general relation between the WCP and CBC indices is shown in Fig. 1 in which 265 WCP indices are plotted against 265 corresponding log-transformed CBC indices. Examination of the resulting scatter plot reveals two general clusters of points, one showing a steeper slope than the other, but both showing positive correlations. The cluster of points surrounding the shallow slope represents birds that are locally abundant but not widely distributed around Wisconsin in winter. Many wintering gulls and other water birds, for example, are very abundant along the Lake Michigan shore. Their CBC numbers are high, but they are reported at very low frequencies, if at all, by birders away from the lakeshore in other parts of the State. Hence, the overall WCP reporting frequencies for the entire State are low even though the CBC tallies are high.

In Table 1, we present the significant correlation coefficients ($r \geq 0.805$, $P < 0.05$) between WCP and CBC indices for the 53 species. There were 21 significant correlations among the 53 species, and 20 of these were positive, a much higher proportion than expected by chance. For many of the species with low correlation coefficients (i.e., < 0.5), one or both of the indices varied little over the 5 years.

Relation Between WCP and BBS Indices

We calculated WCP and BBS indices for 143 bird species in each of 5 years, 1983–87. In Fig. 2 we plot the resulting 715 WCP indices (143 species × 5 years) against their corresponding log-transformed BBS indices. The strong, overall, positive relation between the two sets of indices is apparent. In Table 2 we present the significant correlation coefficients ($r \geq 0.805$, $P < 0.05$) between the five pairs of yearly indices for the 143 species. Of these 10 significant correlation coefficients, 9 are positive, a higher proportion than might be expected by chance. The single negative correlation is for a nocturnal owl that is not well indexed by diurnal census methods. In many of the species for which correlation coefficients were low (i.e., < 0.5) and nonsignificant, there was little or no variation in either the BBS or WCP indices over the 5-year period.

Relation Between WCP and CGOS Indices

We calculated WCP and CGOS indices for two species of migratory raptors, the northern goshawk (*Accipiter gentilis*) and peregrine falcon (*Falco*

Table 1. *Significant correlations between WCP and CBC indices over 5 years.*

Species	Correlation coefficient (*r*)
Red-tailed hawk	0.837
American kestrel	0.879
Ring-necked pheasant	0.895
Herring gull	0.818
Eastern screech owl	–0.815
Red-headed woodpecker	0.919
Hairy woodpecker	0.859
Pileated woodpecker	0.833
Black-capped chickadee	0.989
Brown creeper	0.839
Golden-crowned kinglet	0.893
American robin	0.995
Northern shrike	0.946
European starling	0.950
American tree sparrow	0.882
Snow bunting	0.839
Purple finch	0.839
Common redpoll	0.966
Pine siskin	0.967
American goldfinch	0.839
Evening grosbeak	0.992

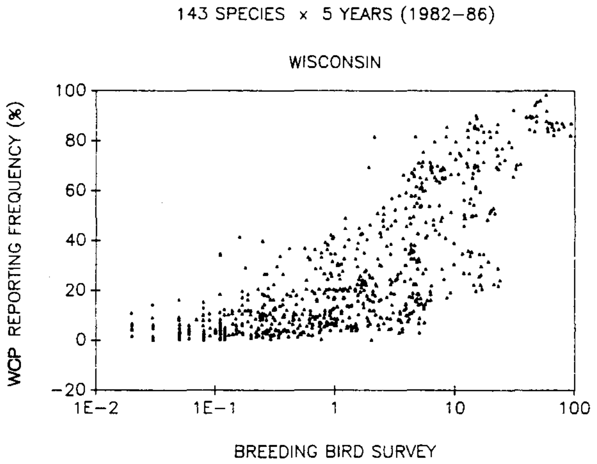


Fig. 2. The relation between WCP reporting frequencies and the average number of birds per BBS route for 143 species over 5 years (1982–86) in Wisconsin.

Table 2. *Significant correlations between WCP and BBS indices over 5 years.*

Species	Correlation coefficient (*r*)
Green-backed heron	0.805
Canada goose	0.868
Cooper's hawk	0.807
Rock dove	0.938
Barred owl	–0.822
Yellow-bellied sapsucker	0.811
Brown creeper	0.893
Eastern bluebird	0.957
Vesper sparrow	0.838
Western meadowlark	0.833

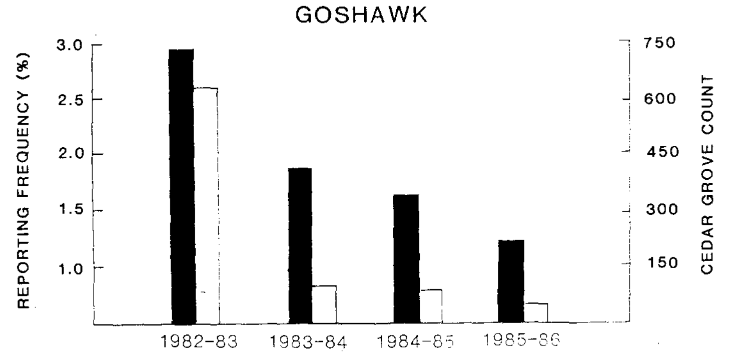


Fig. 3. The relation between WCP reporting frequencies (*solid bars*) and the CGOS counts (*open bars*) of migrating northern goshawks (*Accipiter gentilis*) for the years 1982–86.

peregrinus), during 1983–87. These two species were selected for comparisons because they were known to have undergone major changes in abundance during the period, the goshawk declining in the aftermath of a major crash in snowshoe hare populations in 1981 and the peregrine falcon increasing as populations recovered from the DDT era. In Fig. 3, the close agreement between the WCP indices and CGOS indices for goshawks is obvious. The correlation between the two was high and significant ($r \geq 0.992$, $P < 0.05$). In Fig. 4, the annual WCP and CGOS indices for peregrine falcons are compared, and again close concordance is found. The correlation between the two indices was high and significant ($r = 0.964$, $P < 0.05$).

Discussion

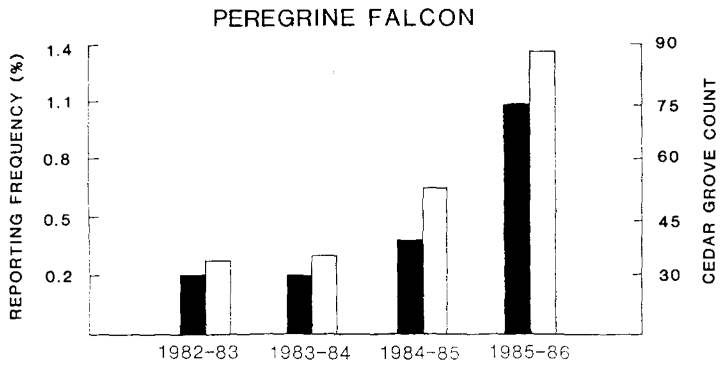
Having demonstrated general concordance between WCP indices and three other independent indices of bird abundance, we feel confident about using WCP indices to monitor trends in Wisconsin bird populations. We are particularly encouraged to discover that WCP indices are sensitive enough to detect year-to-year changes that are known a priori to have taken place in certain bird populations. Two examples bear further discussion.

First, in the case of migrating goshawks and peregrine falcons, WCP indices responded sensitively to known changes in the magnitude of the annual fall migratory movements. These two cases are particularly noteworthy because both of these raptor species are relatively rare. The WCP reporting frequencies for the peregrine falcon, for example, varied from 0.2% to 1.1% between 1983 and 1987, yet even with these low reporting frequencies the checklist data still reflected known trends and paralleled migration counts.

A second example comes from Temple and Cary (1987b) who used WCP data to examine year-to-year variations in the phenologies of migrants. They found that the phenologies of different species showed slight but predictable differences that WCP indices were sensitive enough to detect. Spring arrival dates of short-distance migrants varied considerably between years and were positively correlated with spring temperatures, but spring arrival dates of long-distance migrants did not. In this case a hypothesis was tested with WCP data on year-to-year variations in bird populations, and WCP indices were able to detect yearly differences of only a few days in arrival dates.

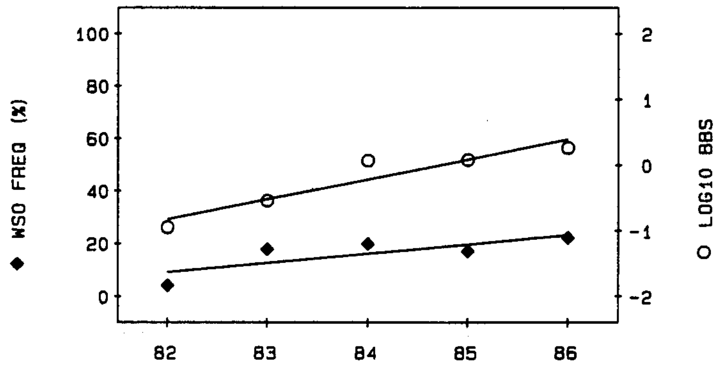
Because the WCP data span only 6 years, it is perhaps premature to discuss using these data to detect "long-term" population trends (i.e., year-to-year changes in abundance that have a consistent upward or downward tendency over many years). Nonetheless, it is possible, again, to look for concordance between trends detected using WCP data and trends detected using other independent data sets (Temple and Temple 1987). From the 1982 to 1987 BBS and CBC data from Wisconsin we identified those species that showed

Fig. 4. The relation between WCP reporting frequencies (*solid bars*) and the CGOS counts (*open bars*) of migrating peregrine falcons (*Falco peregrinus*) for the years 1982–86.



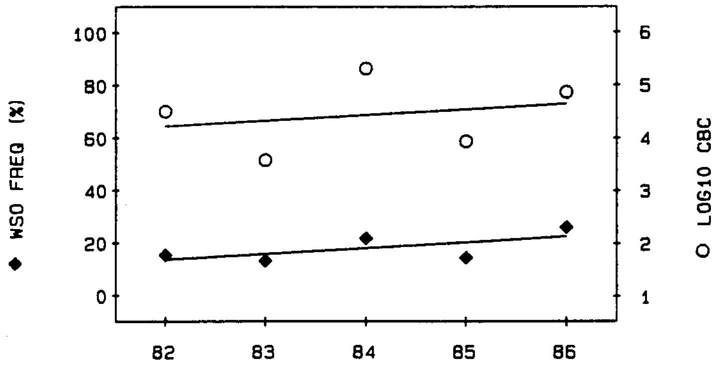
Canada Goose

WCP = -281.9800 + 3.5500 YEAR
LOG10 (BBS) = -26.0043 + 0.3069 YEAR *



Canada Goose

WCP = -170.1000 + 2.2400 YEAR
LOG10 (CBC) = -4.7243 + 0.1090 YEAR



Eastern Bluebird

WCP = -274.7600 + 3.6300 YEAR *
LOG10 (BBS) = -10.3528 + 0.1248 YEAR *

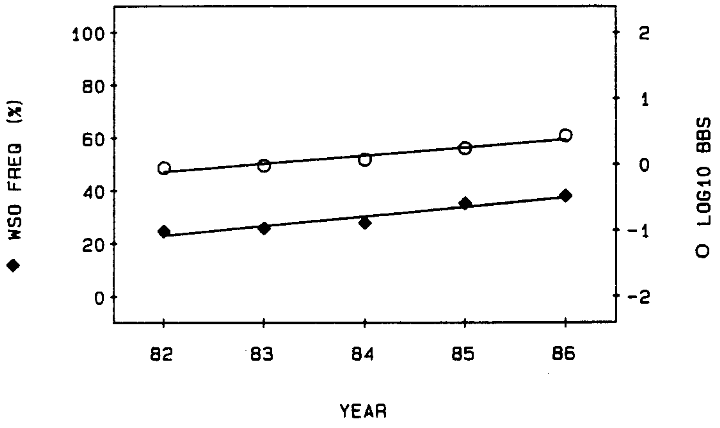


Fig. 5. Comparisons of trend lines determined by linear regression of WCP data and either log-transformed BBS or CBC data.

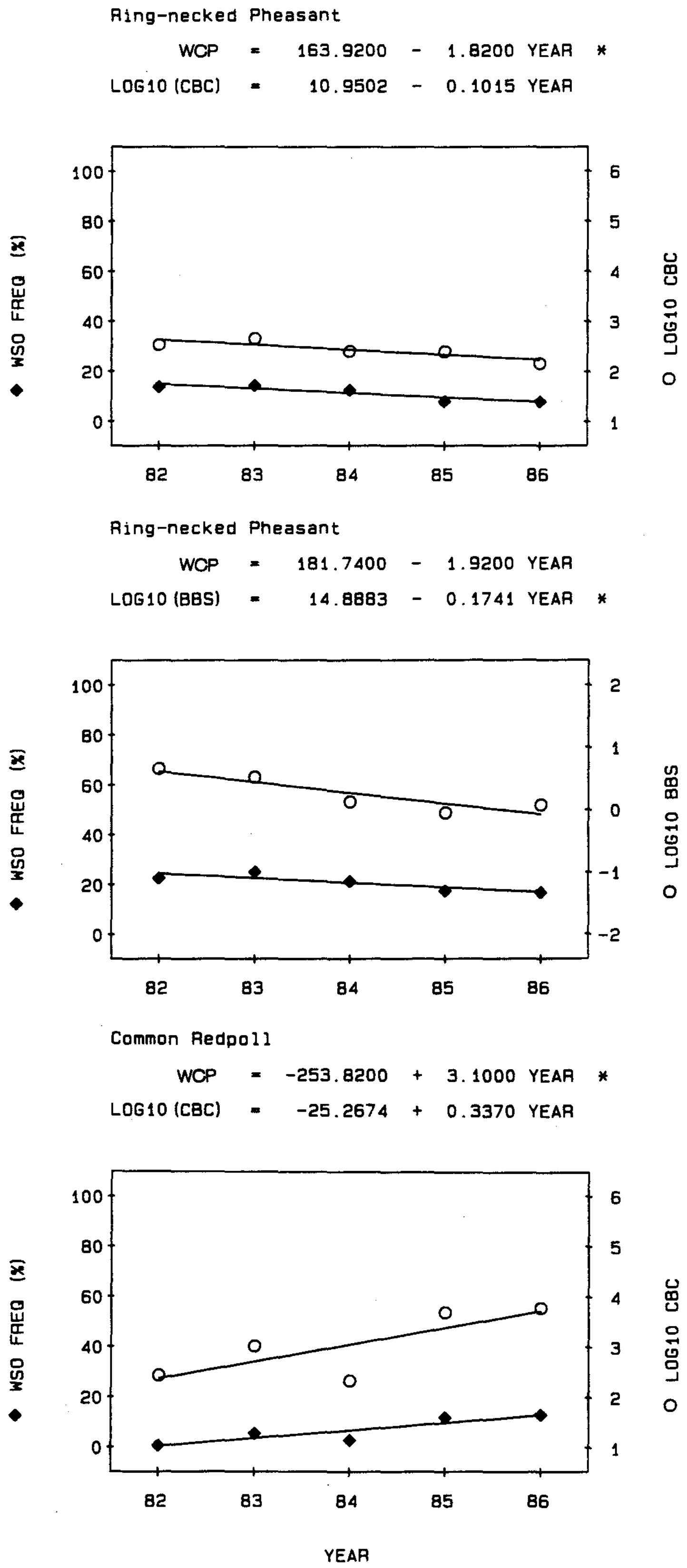


Fig. 5. Continued.

significant 5-year increases or decreases (based on slopes of regression lines being significantly different from zero). In Fig. 5, we compare slopes of regression trend lines calculated using log-transformed BBS or CBC data and corresponding WCP data. Again, a general pattern of concordance is evident in a variety of species, both rare and common.

A final point about using the results of the WCP to monitor trends in bird populations is cost and ease of data collection and management. Bird watchers are obviously willing to participate in the WCP in greater proportions than they are the BBS, perhaps because it caters to their normal birding activities and record-keeping habits (Temple and Cary 1987a). Because of the popularity of the WCP, temporal and geographic coverage has been consistently good. The ease with which data are recorded on optically scannable forms and then transferred to computer-compatible formats is a definite advantage. We have, so far, been able to manage the entire WCP data set (which exceeds 2.92 MB) on desktop microcomputers. These efficiencies have kept costs extremely low in view of the volume of valuable data being handled. Not counting labor (all of which is volunteered), the WCP has annual operating costs of about $1,800 (mostly for forms, optical scanning, postage, and office supplies).

In view of the apparent success of using WCP data to monitor population trends, this program is probably one of the most cost-effective monitoring programs in North America. Furthermore, unlike the BBS, CBC, and other programs that are temporally restricted, the WCP coverage spans the entire year.

Acknowledgments

We are grateful for the cooperation of 431 members of the Wisconsin Society for Ornithology who participated in the WCP from 1982 to 1986. A. J. Temple kept track of them and the 29,892 checklists they submitted for analysis. S. D. Robbins provided us with copies of BBS data for Wisconsin. G. Allez provided us with unpublished records of migrating raptors counted at the CGOS. The WCP received financial support from the A. W. Schorger Fund of the Department of Wildlife Ecology, University of Wisconsin – Madison.

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Detecting Trends in Hawk Migration Count Data

by

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ABSTRACT.—Counts of migrating raptors tend to be extremely variable among both sites and species. We use linear regression, route-regression, and a nonparametric method to estimate population trends from counts of northern harriers (*Circus cyaneus*), peregrine falcons (*Falco peregrinus*), and broad-winged hawks (*Buteo platypterus*). All methods show similar results for northern harrier and peregrine falcon trends, but only the route regression method indicated a decline in broad-winged hawk trends. Because of the small number of migration count sites, statistical power is an important consideration in the analysis of trends in migrating raptors.

Introduction

Monitoring raptor populations over a large area is difficult because raptors nest in low densities compared to other birds, and they are usually secretive and often nest in remote areas (Fuller and Mosher 1987). Furthermore, funds are not available to survey nesting populations of most species. For migratory raptors, one possible method for monitoring population change is to count individuals passing fixed points along their migration paths. The data acquired are known as hawk counts. During migration many species migrate along leading lines, which are environmental and physiographic features (e.g., mountain ridges, coastlines, peninsulas) that result in a concentration of birds (Murray 1964; Mueller and Berger 1967; Alerstam 1978; Richardson 1978). In some instances, hawks have been counted annually for many years at noteworthy concentration areas (Allen and Peterson 1936; Brett and Nagy 1973; Fuller and Titus 1990).

Most early analyses of hawk counts used empirical methods and often employed the "running average"

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technique of plotting data to evaluate trends in counts (Spofford 1969; Hackman and Henny 1971; Nagy 1977; Dunne and Sutton 1986). The methods used often lacked rigor in their assessment of counts that have been shown to have high variation among years (Svensson 1978; Titus et al. 1989a). Robbins (1975) used regression methods to evaluate trends in counts of hawks, but his suggestions have not received wide attention, and his examples were mostly with unstandardized data. Recently, Ward et al. (1988) and Mueller et al. (1988) used more rigorous evaluations to detect trends in counts over time by standardizing their data before statistical analysis.

The use of hawk migration counts for population monitoring has been criticized, in part, because of the high among-year variation in counts and the inability to tease apart the components of variability in counts made at a location (Ulfstrand 1958; Kerlinger 1985; Smith 1985). Much of the among-year variation in counts is presumed to be caused by weather (Richardson 1978; Hussell 1985) rather than population changes. Consequently, Hussell (1981, 1985) used multiple regression techniques to evaluate changes in migration counts after accounting for the effects of weather. This approach is useful when only short-term (e.g., 5 years) and complete weather data are available.

We have approached the problem of detecting trends without accounting for weather effects because these data are not always available, and even if they are the data entry and programming required to conduct these analyses inhibits their timely application. Other recommendations have been made to deal with the problems associated with highly variable count data, such as conducting multiple counts (Harris 1986). We use simple linear regression, a nonparametric method, and route-regression (Geissler and Noon 1981; Geissler 1984) to evaluate trends in hawk count data. These statistical methods provide a basis for objective assessments of trends in counts, but they have not all been previously applied to hawk count data. Therefore, our objectives are to (1) describe some attributes of standardized hawk count data; (2) provide an explanation of a nonparametric trend analysis method; (3) empirically compare the results of different trend analysis techniques; and (4) recommend appropriate techniques for certain applications. To compare methods, we highlight results using data from three species of migrant hawks (northern harrier, [*Circus cyaneus*], peregrine falcon, [*Falco peregrinus*], broad-winged hawk, [*Buteo platypterus*]). These three species typify the variety of hawk count data for which there is interest in detecting trends.

Methods

Study Sites

We demonstrate analyses for detection of trends in hawk count data with examples from six noteworthy eastern United States hawk lookouts (Table 1) where data are recorded on standard forms provided by the Hawk Migration Association of North America (HMANA; Roberts 1985). Count data have been acquired from some of these sites for many years (e.g., >50 years at Hawk Mountain), while at other sites standardized count data were available only from 1980

Table 1. *Names, locations, references for site descriptions, and number of years of hawk count data that were analyzed at each of six eastern hawk lookouts.*

Name and location	Years included in analysis	Total years	References
Hawk Ridge, north shore Lake Superior, Duluth, Minnesota	1972–87	16	Hofslund 1954, 1966
Whitefish Point, northeast tip of Upper Peninsula, Michigan	1980–87	8	Magee 1922; Devereux et al. 1985
Derby Hill, southern shore of Lake Ontario, near Mexico, New York	1979–87	9	Haugh and Cade 1966; Haugh 1972
Hawk Mountain, eastern Pennsylvania	1972–87	16	Broun 1935, 1949
Sandy Hook, Atlantic coast, central New Jersey	1979–87	9	Eynon 1941; Clark 1978
Cape May, Atlantic coast, southern New Jersey	1976–87	12	Allen and Peterson 1936

to 1987 (Fuller and Titus 1990). We arbitrarily chose not to use data before 1972 even they were was available (Table 1).

Hawk Species

We reviewed data from counts of 14 species of Falconiformes, and we performed detailed analyses on counts of northern harriers, peregrine falcons, and broad-winged hawks. Counts for some species are comparatively low (e.g., peregrine falcon, bald eagle [*Haliaeetus leucocephalus*]), others are moderate and vary little among sites and years (e.g., northern harrier, American kestrel [*Falco sparverius*]), while others are high (broad-winged hawk).

We analyzed the total season-long standardized count for a species at a site. The resulting count was standardized in that all days (except those with inclement weather) of the entire migration period were surveyed, and data were reported on the HMANA forms. Other methods of standardization could have been chosen whereby the season-long count would be adjusted. Examples of other adjustments include the count per number of observation days, count per number of observation hours, and count standardized by seasonal or daily averages (Alerstam 1978; Titus and Mosher 1982; Hussell 1985; Ward et al. 1988). Our use of the total season-long count was due in part to some missing information on observation hours and observation days.

Statistical Analyses

Simple linear regression, nonparametric rank-correlation trend analysis, and route-regression trend analysis were used to test for trends in hawk counts among years. We use the term trend to mean that a statistical test reveals a statistically significant change in the counts over the period. We assume this statistical significance is an indicator of some change in the number of raptors. Ultimately, wildlife managers will want to assume that changes in counts are an indication of changes in raptor numbers rather than a result of observer effort, counting methods, or weather.

A consideration for our data is the ability to detect significant trends with only 8 years of counts from a site. Another consideration is serial correlation of the counts, because both simple linear regression and nonparametric rank-trend analyses assume that counts are independent among years. However, tests of serial correlation (time-series) are not applicable to our small sample of years (Neter et al. 1985).

Simple Linear Regression

Testing the significance of the slope of a regression line is one method for analyzing trends (Neter et al. 1985; Holmes and Sherry 1988). This technique can be useful for analyzing trends at a single location over time. Warkentin and James (1988) used the significance of Spearman rank correlation coefficients to evaluate trends, but such methods do not specifically test for trends.

Nonparametric Rank Trend Analysis

Hawk counts often fluctuate considerably among years at a given location. A nonparametric method might be better suited for the detection of a trend than regression methods because it is difficult to account for the year-to-year variability, much of which is presumed to be caused by factors other than population change. In addition, the assumption of homogeneity of variances might not be met with hawk count data. Lehmann (1975) developed a nonparametric statistic to test for trends over time. This was developed as a one-tailed test and can detect the presence of a positive trend (e.g., increasing hawk counts with time). We modified this test to be two-tailed in order to test for the presence of either positive or negative trend. An explanation of the test statistic follows.

For a given location, hawk counts are arranged in ascending order and assigned ranks, with ties receiving the mean of the corresponding ranks (midranks; PROC RANK TIES = MEAN, SAS 1985). The null hypothesis is that the counts are random and do not change with time. In other words, the assignment of the ranks is random. Alternatively, if the counts tend to increase or decrease with time, the ranks would do likewise. The test statistic then is

$$D = \sum (R_i - i)^2 \qquad (1)$$

where R_i is the rank of the ith yearly count and i goes from one to the number of years (N). Small values of D might indicate the existence of a positive trend, and large values of D might indicate the existence of a negative trend.

A null distribution for D can be calculated to determine the significance of a positive or negative trend. This calculation becomes arduous because as N increases the possible number of distinct arrangements of the ranks increases by N! Lehmann (1975) showed that the distribution can be approximated by the normal distribution when a continuity factor of 1 is added to D. The expected value of D is given by

$$E(D) = (N^3 - N)/6 - \sum (n_i^3 - n_i)/12 \qquad (2)$$

where n_i is the number of observations with the ith rank, and the variance is given by

$$\mathrm{Var}(D) = \left[N^2(N+1)^2(N-1)/36\right]\left[1-\sum(n_i^3-n_i)/(N^3-N)\right]. \tag{3}$$

Using these three equations, a z-score can be calculated as

$$\Phi = [\,D - E(D)]\,/\mathrm{Var}(D)^{1/2}\ . \tag{4}$$

A negative Φ (i.e., the calculated D is greater than expected) indicates the possibility of a positive trend. Likewise, a positive Φ (i.e., the calculated D is less than expected) indicates the possibility of a negative trend. The null hypothesis of no trend is then tested using the two-tailed probability.

We used the two-tailed test to detect significant positive or negative trends over time at each site. Lehmann (1975) also expanded the test statistic to test for a positive trend among groups (e.g., sites). For each site, the statistics shown in equations 1–3 are calculated and summed. The z-score calculated is similar to equation 4 and is given by

$$\Phi = \left[\sum D - \sum E(D)\right]/\left[\sum \mathrm{Var}(D)\right]^{1/2}. \tag{5}$$

Again, we modified the test and used the two-tailed probability in order to test for positive or negative trends. Results from this method can be compared with linear and route-regression techniques.

Route-regression Trend Analysis

We used route-regression trend analysis to test for long-term trends in counts of migratory birds (Geissler and Noon 1981; Geissler 1984). This method was developed for use with surveys such as the Breeding Bird Survey (BBS), where individual survey routes were sampled over a number of years (e.g., Robbins et al. 1986). This method is generally applied when a large number (> 20) of routes (sites) are surveyed for at least 5 years. In contrast to BBS data, our data included much larger counts for most species, and only six sample sites. The route-regression technique cannot be used for analyzing trends at a single site. No observer covariates were used in our analyses. We weighted our analyses by the magnitude of the counts (James et al. 1990). The route-regression analyses were conducted by J. R. Sauer.

Results and Discussion

Variability in Counts

Counts varied widely among species and sites. For example, mean counts of golden eagles (*Aquila chrysaetos*) were 9.1/year at Whitefish Point, while counts of sharp-shinned hawks (*Accipiter striatus*) at Cape May averaged 39,632/year. Mean counts of peregrine falcons were usually less than 100 per site per year (excepting Cape May), those of the northern harrier were less than 1,000 per site per year, and broad-winged hawk counts were sometimes of the order 10^4 (Table 2; Figs. 1, 2, and 3). Note that the within-site and among-year variation in counts was not higher for the broad-winged hawk than for other species. Although this species has high variability in absolute counts among years, its coefficient of variation was similar to that of species with lower annual counts. Coefficients of variation averaged 40% for all 14 species at six sites. This variability seems to be inherent in migration count data, and might limit detection of trends over short periods (Svensson 1978). This among-year variation in counts generally is attributed to the effects of weather (Richardson 1978; Kerlinger et al. 1985; Kerlinger and Gauthreaux 1985); therefore, increased standardization of the specific protocol for counting hawks in the field might only reduce the variance by a small amount.

Linear Regression

Linear regression is a useful technique for testing trends at one location, and we found significant trends in 9 of 18 analyses (Table 3). Because the number of years varied among sites, the F-value required to obtain

Table 2. *Mean annual counts of northern harriers (Circus cyaneus), broad-winged hawks (Buteo platypterus), and peregrine falcons (Falco peregrinus) at six eastern hawk lookouts. Coefficients of variation given in parenthesis.*

	Count site					
Species	Hawk Ridge	Whitefish Point	Derby Hill	Hawk Mtn.	Sandy Hook	Cape May
Northern harrier	360.6 (46)	266.8 (46)	729.7 (24)	276.1 (31)	316.6 (41)	1,815.4 (46)
Broad-winged hawk	29,343.3 (44)	4,816.6 (61)	27,573.3 (35)	10,526.6 (55)	160.2 (59)	4,126.1 (111)
Peregrine falcon	12.1 (55)	12.8 (59)	2.2 (44)	11.8 (61)	5.3 (53)	316.4 (64

significant trends also varied. For example, with 8 years of data at Whitefish Point, $F_{\text{crit}.05;\ 1,6\ df} = 5.99$, whereas with 16 years of counts at Hawk Ridge, $F_{\text{crit}\ .05;\ 1,14\ df} = 4.60$. Therefore, we might, on average, expect more statistically significant trends at sites with more years of data, if biologically real trends occurred with equal frequency among sites.

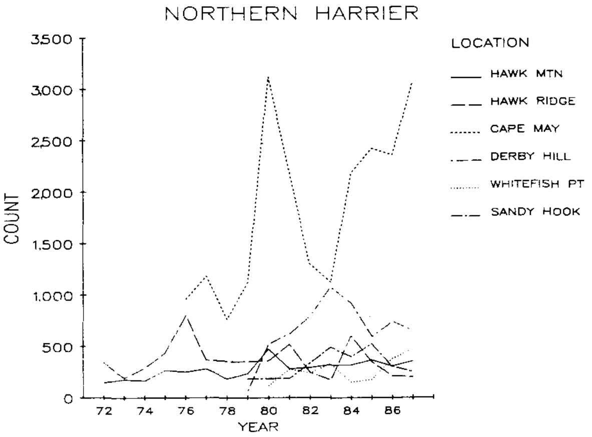

Fig. 1. Annual counts of northern harriers (*Circus cyaneus*) at six eastern hawk lookouts. The number of years of annual counts varies by location.

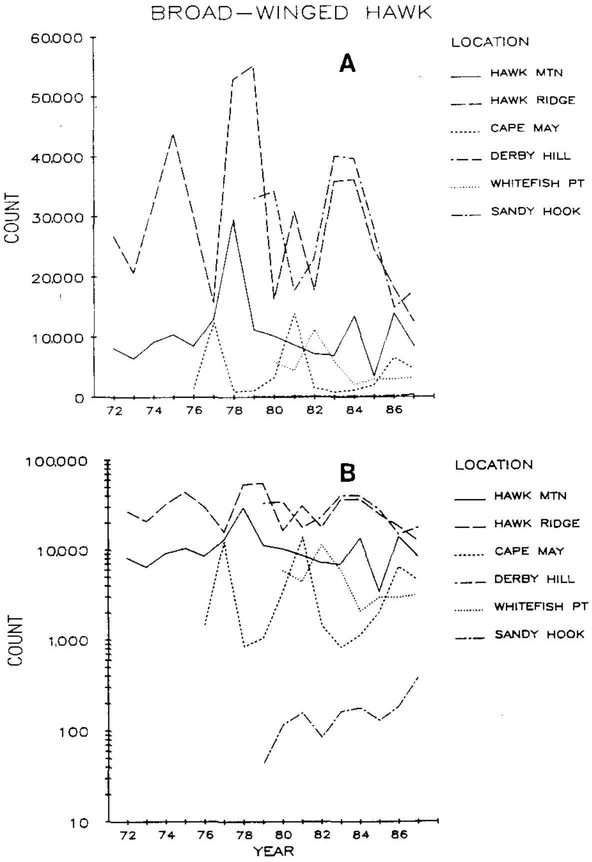

Fig. 2. Annual counts of broad-winged hawks (*Buteo platypterus*) at six eastern hawk lookouts. Counts are plotted both as an arithmetic (A) and a logarithmic scale (B).

Hawk count data are subject to similar concerns of other time-series data. Namely, hawk count data are highly variable (Figs. 1 and 2a), trends might not be linear, and a single regression line might mask details of biological interest. Statistical and nonstatistical methods are available to explore these concerns; however, regression can still be one of the more useful methods for testing a trend. For counts from a single site with less than 10–15 years, data smoothing (Velleman and Hoaglin 1981; Chambers et al. 1983) and more rigorous testing methods (Edwards and Coull 1987) might not be valid alternatives.

Nonparametric Rank Trend Analysis

We found significant trends in 8 of 18 analyses, all of which were the same as the regression method. Only in the tests of the northern harrier counts from Whitefish Point were the results different between methods. The *P* value from the regression analysis was 0.093, and from the nonparametric method it was 0.108, so even in this instance the levels of significance were nearly equal.

The nonparametric method has the appeal that homogeneity of variances over time and a linear pattern need not be assumed. High among-year variability in counts is not of consequence for this nonparametric method, only the order of ranks. Empirically, the statistical power obtained with the nonparametric technique matched that of linear regression, making the technique appealing to those who have data suited to the method. A disadvantage of the nonparametric trend analysis is that there is no slope estimate, so we cannot estimate an annual change, which is routine with regression approaches.

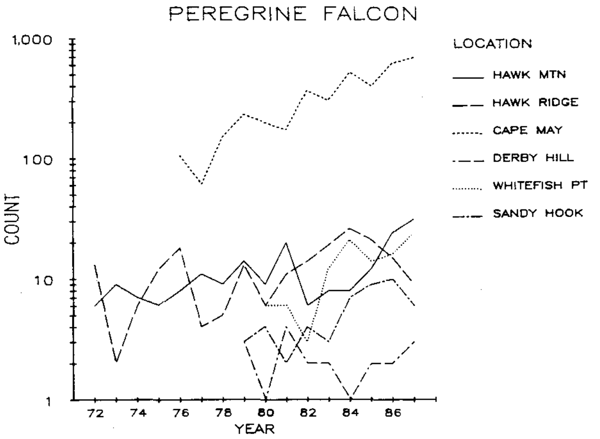

Fig. 3. Annual counts of peregrine falcons (*Falco peregrinus*) at six eastern hawk lookouts plotted on a logarithmic scale.

Table 3. *Comparison of linear regression and nonparametric rank trend analysis techniques based on analysis of single sites.*

	Species					
	Northern harrier		Broad-winged hawk		Peregrine falcon	
Location	Trend[a]	Significance[b]	Trend	Significance	Trend	Significance
Hawk Ridge						
linear regression		NS		NS	Pos.	*
nonparametric method		NS		NS	Pos.	*
Whitefish Point						
linear regression	Pos.	*		NS	Pos.	***
nonparametric method		NS		NS	Pos.	**
Derby Hill						
linear regression		NS		NS		NS
nonparametric method		NS		NS		NS
Hawk Mountain						
linear regression	Pos.	***		NS	Pos.	***
nonparametric method	Pos.	***		NS	Pos.	**
Sandy Hook						
linear regression		NS	Pos.	**	Pos.	**
nonparametric method		NS	Pos.	**	Pos.	***
Cape May						
linear regression	Pos.	**		NS	Pos.	***
nonparametric method	Pos.	**		NS	Pos.	***

[a] Trends indicated are: Pos. = positive; Neg. = negative; blank = no significant trend.
[b] Significance * = $P < 0.10$; ** = $P < 0.05$; *** = $P < 0.01$; NS = not significant.

Route-regression Trend Analysis

Broad-winged hawk counts decreased, and northern harrier and peregrine falcon counts increased significantly when the route-regression trend analysis was applied (Table 4). For the northern harrier counts, three of six univariate regression analyses indicated a positive trend, and the weighted, pooling capabilities of the route-regression method detected an overall positive trend. The analysis weighted most on the high and increasing counts at Cape May (Fig. 1). Despite the large bootstrapped variance, peregrine falcon counts were found to be increasing at a substantial rate, a pattern supported by many other studies (Cade et al. 1988). Only at Derby Hill, where few peregrine falcons were counted (Table 2), was there no detectable trend.

We found the route-regression method interesting in that it detected a significant downward trend in broad-winged hawk counts. Neither univariate method indicated a significant downward trend at any of the six sites (Table 3). It is difficult to correlate the route-regression downward trend with other surveys because broad-winged hawks are not subject to independent intensive surveys as are conducted for some species, such as the bald eagle and peregrine falcon. The BBS is an extensive survey, which obtains some data on broad-winged hawks, and Titus et al. (1989b) analyzed BBS data for broad-winged hawks in

Table 4. *Comparison of route-regression trend analysis and pooled nonparametric rank-trend analysis testing for trends in hawk counts at six eastern hawk lookouts.*

	Route regression method				Nonparametric method	
Species	Total count[a]	Variance	Trend[b]	Significance[c]	Trend	Significance
Northern harrier	5.09	7.05	Pos.	*	Pos.	***
Broad-winged hawk	-2.74	1.23	Neg.	**		NS
Peregrine falcon	15.30	29.83	Pos.	***	Pos.	***

[a] Annualized percent increase or decrease in counts.
[b] Trends indicated are: Pos. = positive; Neg. = negative.
[c] Significance * = $P < 0.10$; ** = $P < 0.05$; *** = $P < 0.01$; NS = not significant.

the northeastern United States. They found an increasing trend in the more-rural regions of the Northeast, and a decreasing trend in the more-developed regions. Therefore, the ability of the route-regression method to detect a long-term trend among these variable counts is of interest.

Absolute counts of broad-winged hawks are notoriously variable (Fig. 2a). Other species that have similar among-year variability include steppe buzzards (*Buteo buteo vulpinus*) at Eilat, Israel (Shirihai 1987), and honey buzzards (*Pernis apivorus*) at Falsterbo, Sweden (Alerstam 1978). The route-regression method might be useful for these species when counts from various sites can be pooled.

In contrast to the route-regression method, the pooled-sites nonparametric method was unable to detect a trend in broad-winged hawk counts. The nonparametric method detected a highly significant ($P = 0.004$) positive trend in northern harrier counts, whereas this trend was only marginally significant with the route-regression method. An important distinction among these two techniques is the weighting of the route-regression method by abundance (counts), compared to no weighing (all sites count equally) with the nonparametric method. It might be possible to modify equation 5 to use a weighted $E(D)$ and Var (D).

Conclusions

Additional exploration of the statistical methods for analyzing hawk count data for the purpose of detecting trends would be useful. Simulation studies of the power to detect trends (Gerrodette 1987), further exploration of autoregressive trend analysis techniques (Edwards and Coull 1987), and studies of the implications of violating assumptions (Harris 1986) would be useful to the many biologists and managers who require trend information. Our study indicated that each of the methods we used had merit under differing situations. For example, researchers at Hawk Mountain are currently analyzing their long series of count data. Regression approaches are aptly being used, although significant positive serial correlation has been found for some of the species-count data (K. Titus, unpublished analysis). It is not known the degree to which positive autocorrelation influences the statistical significance of linear regression approaches and the potential for type I and type II errors, although Edwards and Coull (1987) consider these problems to be serious.

Our nonparametric approach is easy to understand and is useful to indicate only whether counts are increasing or decreasing over time. This method gains statistical power when two or more sites are pooled, and, unlike route-regression, it does not require the large number of sites. The nonparametric method does not weight sites based on counts as does the route-regression method, but a weighting procedure could be incorporated. Finally, the nonparametric statistical methodology is easily programmed, and we have developed a SAS-MACRO program to execute it (SAS 1987).

The route-regression method has intuitive appeal given certain considerations. First, count data have to be available from a number of sites. We believe that data from as few as five sites can be used, even though those interpreting BBS results with the route-regression method advise against using data sets with less than 10 routes. Presently it is not possible to obtain standardized data from 10 hawk count sites. However, hawk count data typically have much larger counts for a species than do BBS routes. Another consideration of the route-regression method is that the sites must be independent, and a final point is that long-term trends are the objective of interest. The option of weighting sites by abundance has appeal because we usually want to make inferences about trends in a population, so sites that sample a larger proportion influence the analysis more than sites with low counts. The route-regression methodology is not easy to understand; however, a personal computer version of the analysis is available.

Our exploration of several techniques for detecting trends in hawk count data provides options for managers who interpret these data for monitoring raptors. We encourage additional investigation of statistical analyses of hawk counts and more research on the influence of weather on counts and monitoring efforts. Understanding the total variance structure is of primary importance for determining the significance of trends in hawk count data, which are inherently variable (Fig. 2a). This is because the statistical methods might not detect a trend when one actually exists, and a type II error results. We suspect that this is the most likely error to occur with hawk count data. Studies to assess the power of the variety of trend analysis methods are therefore important because there are limits to improving the quality of the data obtained in the field.

Acknowledgments

We thank J. L. Ruos and the Fish and Wildlife Service, Office of Migratory Bird Management for initiating the standardized data collection, and the staff and volunteers who collected the data. Data collection was supported, in part, by the Office of Migratory Bird Management through contracts with Cape May Bird Observatory, Derby Hill Bird Observatory, Onondaga Audubon Society, Whitefish Point Bird Observatory, and the Duluth Audubon Society. L. Goodrich and S. Senner of the Hawk Mountain Sanctuary Association generously provided us with their recent data. Our analyses were supported by the Office of Migratory Bird Management and by W. S. Seegar through the Virginia Cooperative Fish and Wildlife Research Unit, with M. R. Vaughan providing technical assistance. We thank J. R. Sauer for conducting the route-regression analyses. Reviews by S. Droege, P. Geissler, and J. Hatfield were very helpful.

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Evaluation of the Sensitivity of Breeding Bird SurveysUsing a Stochastic Simulation Model

by

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ABSTRACT.—A stochastic simulation model was developed to mimic sampling along breeding bird surveys. The model was then used to assess the influence of five variables on the detection of declining bird populations. The variables analyzed were (1) the number of routes sampled in a region, (2) the length of time a population was monitored, (3) the magnitude of the yearly decline in a population, (4) the initial mean number of stops at which a species was detected along survey routes, and (5) the magnitude of variation about the mean number of stops at which a species was detected.

The number of years that surveys are conducted influences the detection of trends most dramatically and accounts for approximately 80% of the variation in accurate trend detection. The number of routes sampled in an area is also very important in detecting trends. These two variables can be directly manipulated by survey organizers and analysts. The magnitude of the yearly decline and the magnitude of the variation in the mean number of stops at which a species occurs also influence the detection of trends, but appreciably less than the former two variables. Using data obtained from Florida breeding bird surveys and results of the simulations, coarse estimates are made of the sample needed to detect population declines for common species.

Introduction

The North American Breeding Bird Survey (BBS) is considered a valuable method for monitoring population trends in common species over large areas (Thompson 1980; Bystrak 1981). The ability of this survey to monitor trends accurately depends on many factors, however, such as the magnitude of the change in the population size of a species over time, the magnitude of stochastic year-to-year fluctuations in population size, the length of time a population is monitored, the number of survey routes sampled in a region of interest, and the sampling error associated with surveys. Evaluating how these factors influence the detection of population trends can be important when deciding the time and effort one should spend conducting surveys of this type. It may take a 10-fold increase in the number of surveys in an area to gain only a 2-fold increase in the reliability of trend estimates for certain species. Of course the level of reliability desired will also influence the intensity of the survey effort required.

Bystrak (1981) used BBS data to document sharp declines in Carolina wren (*Thryothorus ludovicianus*) populations in years following severe winters. Though sharp changes in populations may be detected consistently with breeding bird survey data over short intervals of time, detecting gradual trends that extend over several years or decades may be more difficult, particularly if the sampling effort is relatively small in an area of interest. Many resource-management organizations are interested in monitoring the gradual changes that might occur in a State or Province over time, but very gradual trends may be masked over short periods of time by a number of other factors. In Florida, for example, the common ground dove (*Columbina passerina*) shows an unsteady decline in its frequency at BBS stops over a 19-year period (Fig. 1). This apparent decline would be difficult to detect over smaller periods of time, since there was considerable variation in the frequency of stops at which the bird was detected.

Here I use a simple stochastic model for the occurrence of a species at stops along survey routes to

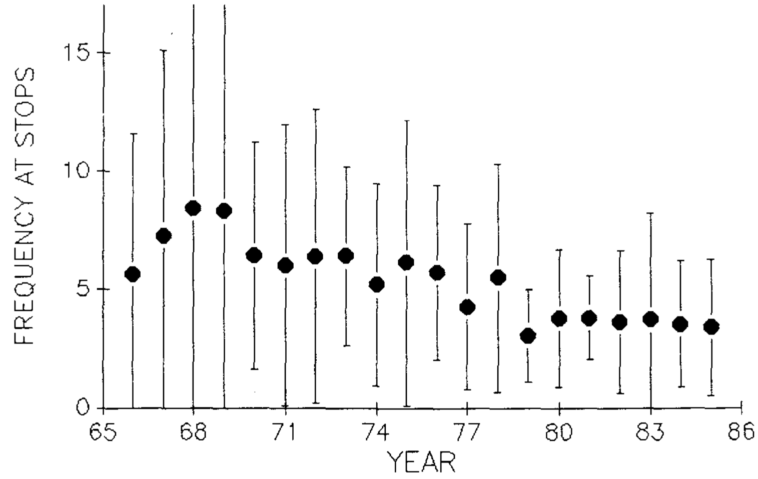

Fig. 1. Plot of mean frequency of occurrence against year for the common ground dove (*Columbina passerina*) in Florida. Error bars represent a single standard deviation about the mean.

evaluate how certain variables affect the sensitivity of these surveys in following gradual population declines. Droege (1990) described the close relation between the occurrence (or frequency) of species at stops and the overall abundance of species encountered along survey routes, and this variable was used in other analyses of bird population trends (Cox 1987; James et al. 1990).

Though several factors may influence the ability of roadside surveys to monitor trends, only five variables were analyzed here: (1) the number of different surveys sampled in a region; (2) the length of time the population was monitored; (3) the magnitude of the decline in a species' population each year; (4) the initial mean number of stops at which a species was detected among surveys; and (5) the magnitude of the yearly variation among surveys for the mean number of stops at which a species was detected. Data collected for 73 species occurring along 37 Florida surveys conducted in 1972 were used to estimate some of these parameters for stochastic simulations.

Model Description and Methods

The simulation model uses the frequency (or rate) of occurrence at stops along a group of survey routes as an index to population size for a species in a region (e.g., stratum, State, or Province). The average frequency of occurrence at stops along all survey routes in a region is set before the initiation of simulations. Variation about the average frequency of occurrence is also set at the outset and follows a uniform distribution. Florida data collected in 1972 indicate that this distribution reasonably approximates the actual variation observed for many species.

The actual number of stops at which a species is detected is determined by a pseudorandom number generator for each route within each year. The simulation tracks the fate of a hypothetical species along a single route over the time period simulated before resetting all variables and conducting a simulation of another route using the same initial set of conditions. The magnitude of variation about the mean frequency among routes is expressed as the coefficient of variation (C.V.; Brown and Hollander 1977) throughout this paper. An example of data generated from this model is presented in Fig. 2.

Several levels for the frequency of occurrence of a species along routes and for the C.V. of frequency among routes were allowed. Initial frequencies of 3, 5, 10, and 15 stops per route were used, as were C.V.'s of 50, 80, and 110%. These ranges were selected based on the Florida BBS data collected in 1972. A plot of the mean frequency of occurrence versus its corresponding C.V. for the 73 species (Fig. 3) showed that the values used in the model approximate those observed for these common species. Note, however, that the relation between these variables is approximately log-linear and that the C.V. increases with increasing frequency at stops. This relation was not specifically accounted for in these simulations, but a few different values for the C.V. were modeled with different values for the frequency along routes.

A declining trend was established among simulated routes by multiplying the overall frequency among routes by a percent change from the previous year. This value then became the new average frequency for the region and was used in the pseudo-random number generation. Annual declines of 5, 10, and 15% were simulated, which reflect moderate, strong, and severe changes in the frequency of occurrence at stops. If no variation about the frequency at stops was allowed, a species with a 5% annual decline would show a $.95^n$ decrease in its frequency n years after the simulation was commenced. The levels of decline modeled here are

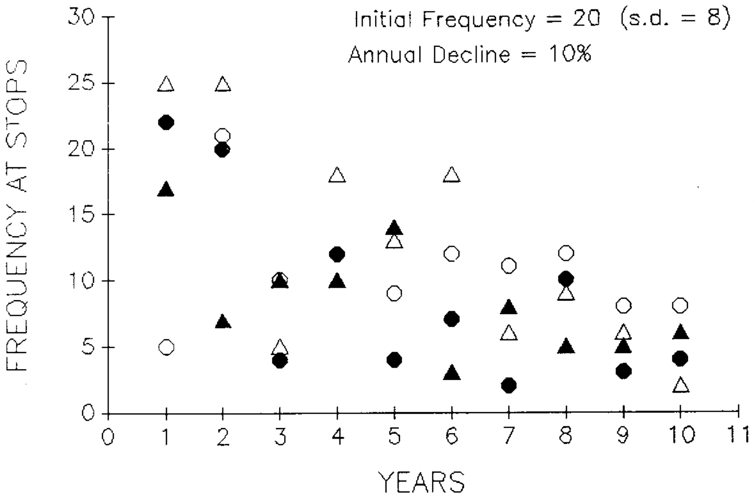

Fig. 2. Example of data generated from the stochastic model for four routes using an initial frequency of 20 stops per route, a coefficient of variation for frequency of 60%, and an annual decline of 10% per year.

probably fairly severe compared to natural levels of decline over large areas.

The influence of the number of routes surveyed within a region each year and the influence of the number of years monitored were evaluated using several arbitrarily selected values. The number of routes was set at 5, 10, 20, and 40 routes per year, and the number of years which the simulations were carried out was set at 5, 10, 15, and 20.

Forty simulations were run for each of the various combinations of years monitored, routes run, proportion decline per year, and so forth. Each of the simulations was then analyzed using linear regression to determine how frequently a declining trend could be detected for the 40 trials run under the same set of conditions. The regression model used was log(frequency) = constant + trend (or slope) $*$ year. Log transformations were made because the yearly change in frequency along survey routes is log-linear (i.e., a proportion per year). This analysis should provide a coarse, statistical projection of the population over the time period modeled. A declining trend was considered accurately detected if a one-sided test for a negative trend achieved a P-value ≤ 0.10. I used this somewhat liberal definition for detection because linear regression analysis may not be an appropriate method for analyzing trends such as these (Geissler and Noon 1981).

There are 550 different unique combinations for the variables analyzed here, but not all of these were modeled. A subset of 220 different combinations was used, selected randomly from the total number of possible combinations. This number of combinations is still large, so a stepwise regression analysis was performed to determine which of the variables best explained the observed variation in the detection of trends. The dependent variable for this analysis was the proportion of accurately detected trends in 40 trials. An

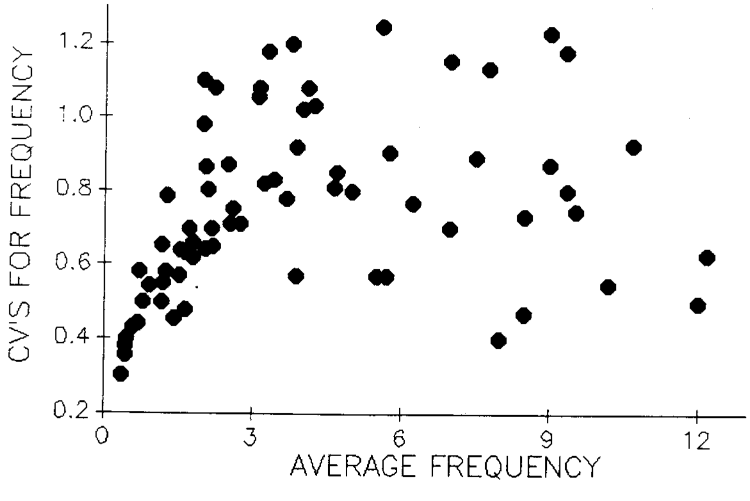

Fig. 3. Plot of mean frequency at stops against the corresponding coefficient of variation for 73 species. Species were detected on 37 surveys conducted in Florida in 1972.

arbitrarily selected alpha value of 0.15 was used to enter or remove variables from this regression analysis.

Results

All five variables entered the stepwise regression analysis with the alpha value used. Within the range of values modeled here, the most important predictor of successful trend detection was the number of years simulated (Table). This variable accounted for about 80% of the sample variance. It was followed in importance by (1) the number of routes surveyed in a region; (2) the percent of annual decline; (3) the coefficient of variation; and (4) the frequency of occurrence along the route. All five variables taken together explained about 97% of the sample variance.

The power curves presented in Figs. 4 and 5 help to demonstrate the influence of some of these variables on detecting declining trends. The influence of route number and the number of years of coverage on trend detection can be fairly substantial (Fig. 4) when other variables are held constant. The influence of the number of routes and the severity of the decline are also fairly large when other variables are held constant (Fig. 5).

Discussion

It is encouraging to see that the two variables exerting the greatest influence on detecting simulated trends are variables that can be directly manipulated by survey organizers. The number of years a population is monitored (or simulated) and the number of routes surveyed in a region each year account for most of the variation observed here in trend detection. These variables reflect the level of commitment given to such surveys, and it is especially important to carry out surveys over many years.

Within the range of values evaluated here, other species-specific traits, such as a species' relative frequency on surveys, the year-to-year variation of a species among survey routes, and a species' annual rate of decline, affect the detection of trends in these simulations less so than do the length and intensity of sampling. The relations between accurate trend detection and the C.V. among survey routes and rate of decline are intuitively obvious. The smaller the variation in frequency among routes, the easier it is to detect trends accurately. It is also easier to detect trends if the rate of annual decline is greater. The negative relation between the rate of occurrence at stops and the accurate detection of trends may be an artifact of the simulation or the regression techniques used here.

The C.V. for the frequency at stops might be reduced by repeatedly sampling survey routes each year (e.g. three surveys of each route) or by collecting habitat information along routes and incorporating these data into trend analyses. The reduction in C.V. would have to be moderately large, however, for this measure to outweigh the potential contribution of simply adding additional routes in a region or extending the duration of the survey period.

Organizations interested in monitoring bird populations over small areas (e.g., a State or Province) often ask how intense the sampling effort must be to detect a persistent trend in a species, given a desired level of confidence. Such estimates might be made using breeding bird survey data for the area of interest, but it is relatively difficult to hold all of the relevant conditions constant or to have knowledge of underlying values for many of the estimated parameters. The number of routes surveyed in Florida each year, for example, has fluctuated considerably since the inception of breeding bird surveys in 1966, and only 17 routes have been sampled consistently since 1969 (Cox 1987).

The stepwise regression equation obtained above could provide a coarse "guesstimate" of the sampling intensity needed to detect a declining trend (given the criterion used here for successful detection, namely linear regression analysis with a one-tailed P-value $\leq$ 0.10). As an example, estimates of the mean frequency and C.V. observed for species detected on Florida breeding bird surveys in 1972 were used in conjunction with the stepwise regression equation to approximate the number of routes needed to detect at least a gradual 5% decline over a 5-year period. The values for frequency of occurrence and C.V. are not

Table. *Stepwise regression analysis for five variables used to predict the variation in the proportion of successfully detected trends. Variables are listed in the order in which they entered the model.*

Variable	Coefficient	R^2
Years of coverage	0.056	0.817
Routes covered	0.009	0.891
Annual decline	4.287	0.910
Coefficient of variation for frequency	−0.345	0.957
Frequency at stops	−0.008	0.968

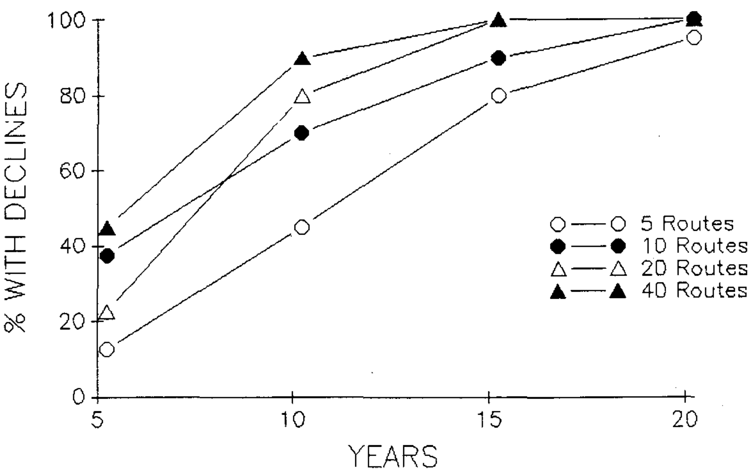

Fig. 4. Plot of the effects of number of routes and years of coverage against the proportion of accurate trend detections for 40 trials. Values for percent decline per year, initial frequency, and coefficient of variation were held constant at 10%, 5 stops, and 60%, respectively.

presented here for each species, but the number of routes needed ranged from 57 to 109 for all species analyzed. The number obtained for each species is a very coarse estimate of the number of routes on which the species would need to occur to be about 90% sure of accurately detecting at least a 5% annual decline in the species. These estimated samples are likely to be off by a fair margin, since this analysis extrapolates well beyond the number of routes (40) allowed for in the simulations. In addition, the family-wide error rate resulting from an analysis extended to all 73 species would lower the level of confidence.

By increasing the number of years that this group of species is monitored, however, considerably fewer surveys would be needed to detect this level trend. To detect the same trend over 10 years requires 26–66 routes, and to detect the same trend over 15 years requires a range of 8–32 routes.

The importance of detecting declining trends early versus the cost of providing a sufficient level of sampling can also be evaluated with the type of information provided earlier. For example, the average number of routes that these 73 species were detected on in 1972 was 21.3 (s.d. = 9.2), or roughly 60% of those surveyed that year. Thus, a two- to fourfold increase in the number of Florida routes seems appropriate if the goal of the monitoring program is to detect gradually declining trends over a 5-year period. The number of surveys in Florida was doubled in 1987, but data for this and later years have not been analyzed. An even larger sample is probably needed to ensure that many uncommon species are present on a sufficiently large number of routes to satisfy this goal. The establishment of nonrandom routes to sample areas containing rare species (or groups of rare species) may be another method of increasing detection levels.

Breeding bird atlas projects (Udvardy 1981) are another monitoring tool that might be considered for monitoring rare or uncommon species over one to two decades, though atlas projects are probably less effective in monitoring trends for common species over short periods of time. The annual cost of the atlas

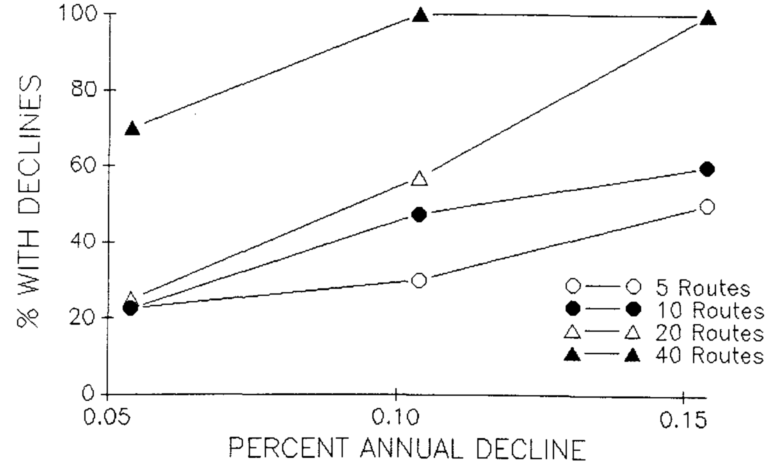

Fig. 5. Plot of the effects of percent annual decline and the number of routes sampled against the proportion of accurate trend detections for 40 trials. Values for years of coverage, initial frequency, and coefficient of variation were held constant at 5 years, 15 stops, and 60%.

project in Florida, however, is nearly 15 times that of the current cost of the State's breeding bird survey activities. (This estimate does not include administrative and data entry services provided by the U.S. Fish and Wildlife Service.) Such costs need to be carefully considered, and there have not yet been any temporal comparisons made of atlas data obtained for a region. Completely novel survey techniques may be needed to monitor some rare populations efficiently (Sudman et al. 1988).

Droege and Sauer (1987) assessed the statistical significance of trends if a species was present on at least 10 routes in a stratum or Province. Though their analysis considered changes in abundance rather than frequency at stops (as modeled here), the two indices to population size are comparable because there is a strong, positive correlation between them (Droege 1990). Again, using the success criterion defined here and data for Florida birds sampled in 1972, this minimum sample would detect an annual 5% decline about 43–83% of the time over a 5-year period, depending on the species. The same sampling intensity would detect more than 99% of the declines if losses were 15% per year over the same period. Though these estimates of requisite sampling intensity are crude, a more strict definition for a sufficient sample may be needed to ensure accurate detection of certain gradual trends over short periods (< 10 years).

The minimum samples used (consistent occurrence on at least two routes) in a 15-year analysis of Florida data (Cox 1987) are inadequate for several uncommon species that may be undergoing gradual declines. For the 73 species observed in 1972, annual declines must fall in the 3.5–14.4% range to be detected over this 15-year period. This is the average minimum level of decline that would be detected approximately 90% of the time with the regression method applied here to the simulation data.

The measure of abundance along routes might enhance the detection of trends along survey routes, but this is more difficult to model and adds another level of complex variation to the problem (Bart 1985). There are problems with this measure that may decrease its effectiveness (James et al. 1990). The cyclic nature of certain populations may also make it much more difficult to estimate trends except with data sets that extend over many years.

Acknowledgments

I thank C. Bunck and J. Hatfield for helpful comments on an earlier draft of this paper.

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Influence of Observer Effort on the Number of Individual Birds Recorded on Christmas Bird Counts

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ABSTRACT.—Observer effort affects results of all counts, surveys, and censuses. Observer effort varies widely in Audubon Christmas Bird Counts; therefore, we propose a method to estimate for each species the number of individual birds that would have been reported (count) if effort had been standardized. We use party-hours or party-miles to measure observer effort. We modeled the relation between count and effort using a nonlinear regression of the form $\mathrm{CT} = e^{A}X^{B}YR^{C}$, where CT = count, X = effort measured in party-hours or party-miles, and YR = year. We chose this model because it covers all three relations that we documented between count and effort: (1) count increases linearly with effort ($B = 1$); (2) effort has no apparent effect on count ($B = 0$); and (3) count increases with effort, but at a steadily declining rate ($0<B<1$). The year variable is included in the model because the average observer effort per Christmas Bird Count has increased steadily over the years. The nonlinear regression is used to obtain the best estimate of B ($\hat{B}$) for each species. We use the estimate of B ($\hat{B}$) and a standard value (SV) for effort to modify all counts to a number that would be expected if the effort had been the standard value, using the equation $\mathrm{SCT} = \mathrm{CT}(SV/X)^{\hat{B}}$. Two case studies suggested that accounting for effort may be more important for a species that achieves high levels of abundance at some locations in some years (American black duck, *Anas rubripes*) than for a species that rarely has more than one or two individuals per location per year (northern goshawk, *Accipiter gentilis*).

Introduction

Observer effort affects results of all counts, surveys, and censuses. Observer effort is strictly controlled in the roadside surveys of the U.S. Fish and Wildlife Service: the Woodcock Singing-grounds Survey, the Mourning Dove Call-count Survey, and the Breeding Bird Survey. Differences in observer effort may affect the results of atlases and checklists, spot-mapping censuses, banding studies, raptor migration counts, and counts of breeding colonial waterbirds. We suggest a new method of compensating for effects of observer effort in Christmas Bird Counts (CBC's). This method relies on empirically determining a species-specific relation between effort and number of individual birds reported (count) and using that relation to estimate the number of individuals that would have been reported for a particular location in a particular year if effort had been standardized. This method is similar to one used by Lack (1986) for the atlas of wintering birds in Britain and Ireland.

Measures of Effort on CBC's

It was realized from the beginning that effort affected the number of individual birds recorded on CBC's (Chapman 1900). Since the early 1950's, effort on CBC's has been measured in party-hours and party-miles; in addition, number of observers and number of parties is recorded for each location each year. A party is a group of birders traveling together and remaining within sight or sound of each other. Party-miles are the number of miles traveled by all parties on a CBC; if six people travel 100 miles during the day in two cars, the total number of party-miles is 100 if the cars travel together but 200 if the cars travel separately. Party-hours are the number of hours spent looking for birds. Like party-miles, party-hours are accumulated by groups. If six people travel together for 6 h, they accumulate 6 party-hours; if they split into two groups for 2 h, they accumulate 4 party-hours. Party-miles are heavily influenced by the amount of time spent in a car and are most useful for species that can be spotted from cars. Party-hours are more useful for birds that are seen and identified on foot. The three measures of effort (observers, party-hours, and party-miles) were correlated for North America in 1963–83 (Pearson Product-Moment Correlations; $N = 21{,}430$): observers and party-hours, 0.74; party-hours and party-miles, 0.66; party-miles and observers, 0.61. Because of these correlations, it may not matter which index of effort is used for many species. The use of party statistics rather than individual statistics derives from the belief that the number of individual birders in a group has less effect on the probability of detecting individual birds than does the number of groups (but see Preston 1979 and Bart 1985). This assumption remains untested for situations similar to CBC's; a promising avenue for future research is to determine how much residual variation in the number of birds reported can be accounted for by the number of individuals per party after the effects of party-hours and party-miles have been determined.

Differences in the Kinds and Amounts of Effort on CBC's

There are four major ways of looking for birds on a CBC: (1) self-propelled (e.g., foot, skis, bicycle, snowshoes) during daylight; (2) motor-powered (e.g., car, boat, snowmobile, golfcart, airplane, helicopter) during daylight; (3) stationary (at bird feeders) during daylight; and (4) at night (both self-propelled and motor-powered). The four kinds of effort are reported separately for each CBC location each year; unfortunately, the species and individuals seen are not reported separately. Thus, it is difficult to study the relative abundance of feeder birds or night birds because, for these groups, individuals are recorded by more than one method. Consequently, it is difficult to determine the effect of varying effort on the number of individuals recorded. Therefore, we recommend that birds seen at feeders or at night be reported separately from birds seen by observers traveling by car or foot during the day.

In addition to the four kinds of effort, wide differences exist in amount of effort both within counts among years and among counts within years. The differences exist for all three measures of effort; for example, differences occur in party-hours both within and between years (Figs. 1 and 2). In addition, there are important changes in party-hours within count locations (Table). With these differences in effort, especially within years and over many years, it is vital to consider whether or not effort is affecting the number of individuals reported and, if necessary, to correct for effort.

Possible Relations Between Count and Effort

Traditionally, number of individuals reported on a CBC is divided by party-hours or party-miles to create an index of abundance for each species at each location each year (Bock and Root 1981). This adjustment assumes not only that the number of individuals reported increases linearly with effort, but also that the line representing the relation between count and effort passes through the origin (i.e., no effort implies no birds counted). This is exactly the relation we found for the red-tailed hawk (*Buteo jamaicensis*) using data from the 48 contiguous States and southern Canada for 3 years in the early 1970's and 3 years in the early 1980's: a highly significant linear relation between count and effort ($\hat{B}$ [slope coefficient] $= 0.007$; $t = 32.0$; $P = 0.0001$) and a nonsignificant y-intercept coefficient (-1.30; $t = -1.6$; $P = 0.108$; Fig. 3).

However, Bock and Root (1981) noted that there should be some species for which effort has no effect on number of individuals reported. These are primarily species that occur in habitats that are small and can be covered in a few hours or less and that are known to be good habitats for birds. Presumably, count organizers send participants to these areas even if there is very little time to count birds. Because the habitat covers a small area, addition of more hours and miles will not increase coverage in that habitat; thus, few if any individuals of the species preferring that habitat will be added.

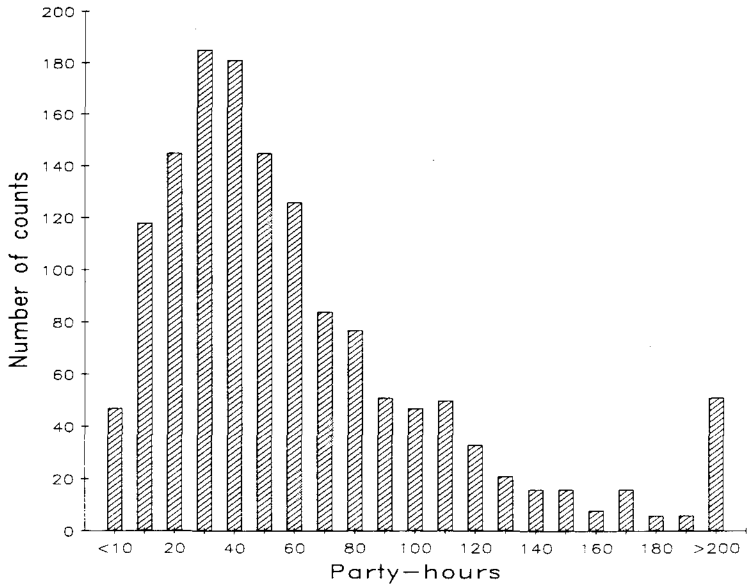


Fig. 1. Distribution of party-hours at individual Christmas Bird Count locations in North America during the winter of 1982–83 showing variation in a single CBC season.

Fig. 2. Mean number of party-hours spent on Christmas Bird Counts in North America during the winter of 1962–63 through the winter of 1982–83. The mean was calculated for each year to remove the effect of variation among locations within years, which was shown in Fig. 1. Note that the between-year variability for this period is much less than the within-year variability for the winter of 1982–83 (Fig. 1). Changes through time within CBC locations are shown in the Table.

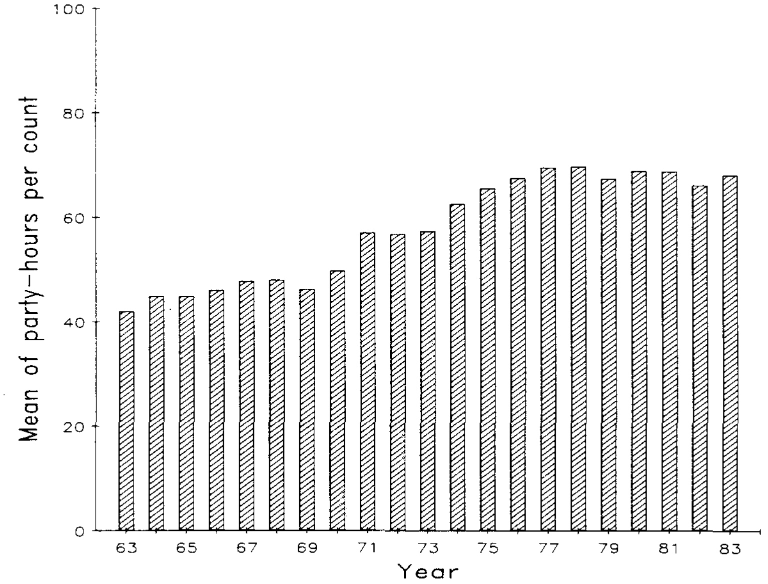


Table. *Change in party-hours within particular count locations (1950–82).*[a]

Time span[b]	Number of locations	Locations with increase (%)	No statistically significant change (%)	Locations with decrease (%)
8–10	92	28	68	4
14–24	302	52	44	4
25–32	363	76	22	2

[a] A simple linear regression was performed on party-hours for each location. If the slope showed a statistically significant ($P < 0.05$) increase or decrease, then the location was assigned to the increase or decrease category; otherwise the location was assigned to the category entitled "No statistically significant change."

[b] The number of years between the first CBC at a particular location and the most recent one. For most locations, all intervening years provided data for the regression.

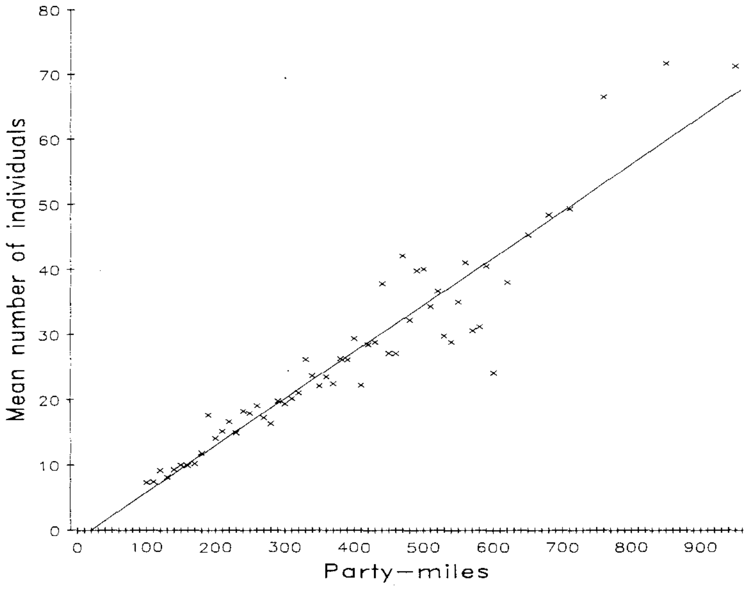


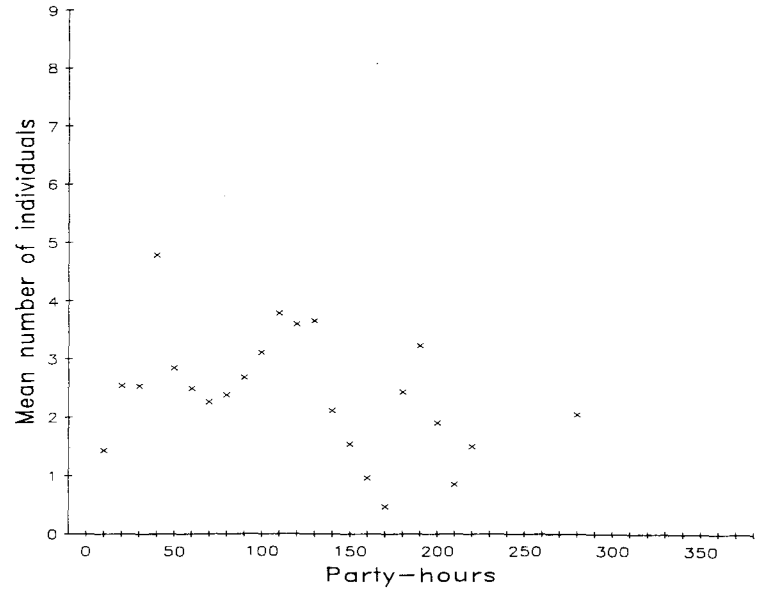
Fig. 3. The relation between count and effort for red-tailed hawks (*Buteo jamaicensis*). The data points represent means of counts by 10-party-mile intervals using data for all North American locations with at least one red-tailed hawk during 1 of 3 years in the early 1970's or 3 years in the early 1980's. The statistical test (see text) used count and party-miles for each location for each of the 6 years.

The bald eagle (*Haliaeetus leucocephalus*; Fig. 4) and mallard (*Anas platyrhynchos*; Fig. 5) seem to be good examples of species that lack a positive relation between count and effort. There was no significant relation between count and effort in the bald eagle ($\hat{B} = -0.063$; $0.05 < P < 0.10$), using data from the 48 contiguous States for 3 years in the early 1970's and 3 years in the early 1980's (Fig. 4). In fact, there was a significant negative relation between count and effort in the mallard ($\hat{B} = -6.61$; $t = -3.66$; $P = 0.0003$; Fig. 5), including data from the United States and southern Canada east of the 100th meridian during 1949–50 through 1981–82.

The negative relation between count and effort in the mallard and bald eagle may be due to the "national wildlife refuge effect": Good wetlands areas are highly valued by birders, thus an area with good wetlands may be chosen as a CBC site even if it is far from urban areas. Such a CBC will have relatively low effort because of its distance from population centers. In contrast, areas near population centers will be chosen as CBC sites and will have high effort even if they lack wetlands.

Finally, Preston (1979) and Johnson (1981) noted that there should be cases where count increases with effort, but not linearly with a zero intercept. There are two general cases: (1) a linear increase, but nonzero intercept,

Fig. 4. Relation between count and effort in the bald eagle (*Haliaeetus leucocephalus*).



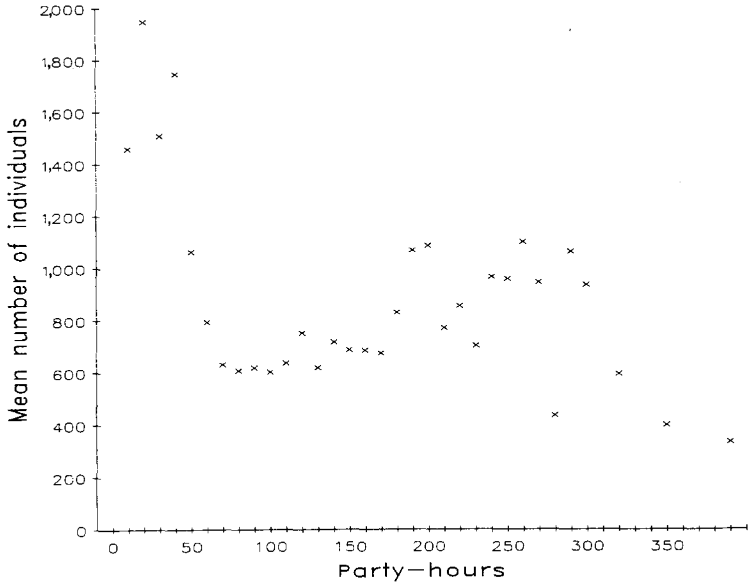


Fig. 5. Relation between count and effort in the mallard (*Anas platyrhynchos*).

and (2) the rate of increase in numbers declines as effort increases. Species that show these patterns might be more abundant in small high-quality habitats, but should also be found in lower numbers in other parts of a count circle.

A complicating factor is the relation between count and effort varies with a number of variables: habitats, weather, latitude, the relative abundance and conspicuousness of a species in an area, and so forth. Therefore, every species on every count circle on every count day should have a unique relation between count and effort. Unfortunately, we only have one data point for each count circle on each count day. It is possible to control for the effects of a few of these variables, but it is not practical to include all of them as variables in an equation used to calculate their effect on the number of individual birds reported.

We are especially concerned with two variables that affect the relation between the number of individual birds reported and the amount of effort: time and human population density. Christmas Bird Counts are clustered near human population centers, and CBC's near high human population densities have, on average, higher effort than CBC's far from human population centers. Many bird species avoid areas of high human population density, for a variety of reasons. Thus, any study of the effect of effort on the number of birds reported on CBC's should control for human population density. Unfortunately, we do not have any measure of human population density for CBC locations, and we must defer this aspect for future study.

The amount of effort on CBC's has increased through time (Fig. 2). The rate of increase was even greater before 1963. Thus, for any species with a time trend in population, time must be included as a continuous variable in the equation to properly measure the effect of effort on the number of individual birds reported. Thus, we have included year as a continuous variable in this study.

Recommended Steps in Analysis of CBC Data

Despite the multitude of factors affecting the relation between count and effort for each species, we assumed for this study that the relation between count and effort is similar at each location within the species' range. We used the following procedure to evaluate specific relations between count and effort:

1. We included all data for all years from all count locations where the species had ever been recorded, and we excluded all count locations where the species had never been recorded. Thus, we included many zeros from locations from which a species had been reported only once or only a few times in 21 years, but we excluded many zeros from locations where the species had never been recorded. The decision of which zeros to include or exclude greatly affects the relation of count versus party-hours or party-miles. However, the only quantity estimated from the relation that is used in our suggested method is the coefficient that governs the slope on the log scale (B, in equation (1)). This coefficient is only slightly affected by the inclusion of many zeros.
2. Next, we did a linear regression of count versus effort, including a year term. If the slope was nonsignificant, zero, or negative, we could not be certain that effort had no effect on the counts, but we could say that other factors were so important that they overwhelmed the influence of effort. For these cases

(e.g., bald eagle and mallard; Figs. 4 and 5), number of individual birds reported for each CBC is recommended for use in studies of relative abundance.

3. Alternatively, if the slope of count versus effort was positive and significantly different from zero, then we corrected the actual number of individuals reported to a number that would be expected if the effort were standard. The following sections are devoted to specific recommendations for this procedure.

4. The next decision was to determine a measure of standard effort. We chose a number near the mean of the effort on all counts in the area and during the period chosen for the study. Choosing a larger number requires too much extrapolation, and choosing a smaller number might minimize differences in counts. For the 21 years between the 1962–63 count and 1982–83 count, the mean for party-hours was about 50 and the mean for party-miles was about 300; these values are used in this paper.

5. The next decision was to determine how to model the relation between count and effort. We have already shown that division by party-hours or party-miles is appropriate for some species, while actual counts suffice for others; our challenge was to come up with an appropriate treatment for other situations.

Nonlinear Regression of Count Versus Effort

Initially, we tried log-log regression, but the results were not completely satisfactory, primarily because data for many species include a large number of zero counts, and log-log regression requires adding a constant to all zero counts. When there is a large number of zero counts, adding the constant distorts the relation between count and effort.

Our second approach was to fit nonlinear models of the form

$$\mathrm{CT} = e^{A}(X)^{B}(YR)^{C} \qquad (1)$$

where CT = count (the number of individuals), A is the intercept on the log-log scale (and the initial slope on the original scale), X = effort expressed as party-hours or party-miles, B is the slope on the log-log scale (and the change in slope on the original scale) for the effect of effort, YR = year, and C is the slope on the log-log scale for the year effect. We chose this model because it covers all realistic cases where count increases with effort. The model has the valuable feature that the curve passes through the origin, reflecting the fact that no birds can be reported if no effort has been expended. We cannot conceive of a realistic situation in which the number of birds reported for an individual CBC would decrease with increasing effort, nor one in which the number of birds reported would increase exponentially when effort increases linearly. Thus, B must remain between zero and one. If $B = 0$, then count does not increase with effort; if $B = 1$, then count increases linearly with effort. For all intermediate values, count increases with effort, but the returns diminish with increasing effort.

This model is the equivalent of a linear log-log regression, but is estimated on the original scale. The advantage of estimating the relation on the original scale is that it avoids the problems with zero counts. We used PROC NLIN in the SAS statistical package (SAS Institute, Inc., Cary, North Carolina) on the Cornell University mainframe computer. We began with a log-log regression to get starting values for the slope and intercept parameters, and then we used these starting values to run PROC NLIN. Theoretically, we should have used a weighted nonlinear regression so that variance was weighted proportionally to the mean; however, weighted nonlinear regression proved impractical because of its great expense with large datasets. Unweighted nonlinear regression seemed to provide a reasonable approximation of the results to be expected from the weighted procedure.

From both the log-log regression and the nonlinear model we estimated parameters A, B, and C. We used the estimate of B ($\hat{B}$) to transform all counts (CT) into standard counts (SCT) that would be expected if effort were equal. To use $\hat{B}$ in this way, we had to allow A to vary for each count (CT) and effort (X). We used the following equations:

$$\mathrm{SCT} = \mathrm{CT}\left(SV/X\right)^{\hat{B}} \qquad (2)$$

where SCT = standard count, CT = count, SV = standard value (50 in party-hours, 300 in party-miles) and X, YR, and $\hat{B}$ are as before. We derived equation (2) from equation (1) in the following manner: Because we are interested in what a standard count (SCT) would be if there had been a standard effort (50 party-hours or 300 party-miles), we used the equation

$$\mathrm{SCT} = e^{A^*}(SV)^{\hat{B}}(YR)^{\hat{C}}$$

(based on equation (1)) where A^* is any value that makes the equation fit through the point (CT, X) using the $\hat{B}$ determined for the species. Because

$$\mathrm{SCT} = e^{A^*}(SV)^{\hat{B}}(YR)^{\hat{C}}$$

(equation (1)), it follows that

$$A^* = \ln(\mathrm{CT}) - (\hat{B}\ln(X)) - (\hat{C}\ln(YR))\,. \qquad (3)$$

By replacing equation (3) in the modified version of equation (1), it follows that

$$SCT = e^{\ln(CT) - (\hat{B}\, \ln(x)) - (\hat{C} \ln(YR))}(SV)^{\hat{B}}(YR)^{\hat{C}} \quad (4)$$

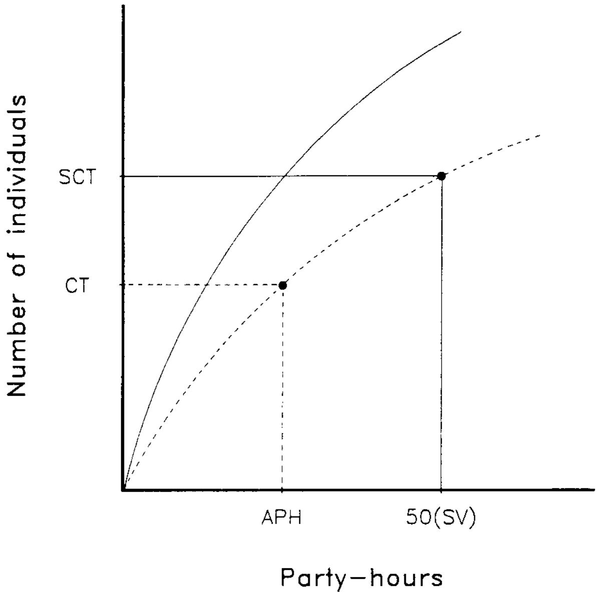


Fig. 6. Graphical representation of our proposed method of creating standard counts from actual counts using a species-specific relation between count and effort. The *solid line* represents the empirically determined relation between count and effort. The *dotted line* represents a line with the same "change in slope" (B), but with a different "initial slope" (A*) that allows the line to pass through the actual point for a particular CBC result. The standard count is the y-value for the point where the *dotted line* intercepts the x-value for the standard count (50 party-hours).

This equation is mathematically identical to equation (2), which is the most convenient form for calculating standard counts. The process of deriving standard counts from actual counts is shown graphically in Fig. 6.

These standard counts are now ready to be used to compare relative abundance through space and time.

Two Case Studies: Northern Goshawk and American Black Duck

The northern goshawk (*Accipter gentilis*) is one species for which the relation between count and effort does not fit either of the two classic models (Fig. 7). In Fig. 7 we show the relation between count and effort in four different ways: (1) using the nonlinear model; (2) and (3) using two log-log regressions (with two different constants added to zeros before taking the logarithm); and (4) using means from the real data. Our visual interpretation of this figure is that the nonlinear model follows the actual data more closely than do the two log-log models. Our decision on the relation between count and effort affects our impression of the population dynamics of northern goshawks from 1963 through 1983 (Fig. 8). Using raw, unmodified counts, the northern goshawk population in the most recent 3 years (1980–81 through 1982–83) was 292% of the population in the earliest 3 years (1962–63 through 1964–65). When dividing the raw counts by party-miles, the early 1980's goshawk index was 236% of the early 1960's goshawk index. Finally, by calculating standard counts as recommended earlier, the 1980's goshawk index was 243% of the 1960's goshawk index.

The American black duck (*Anas rubripes*) is another species with a nonlinear relation between count and

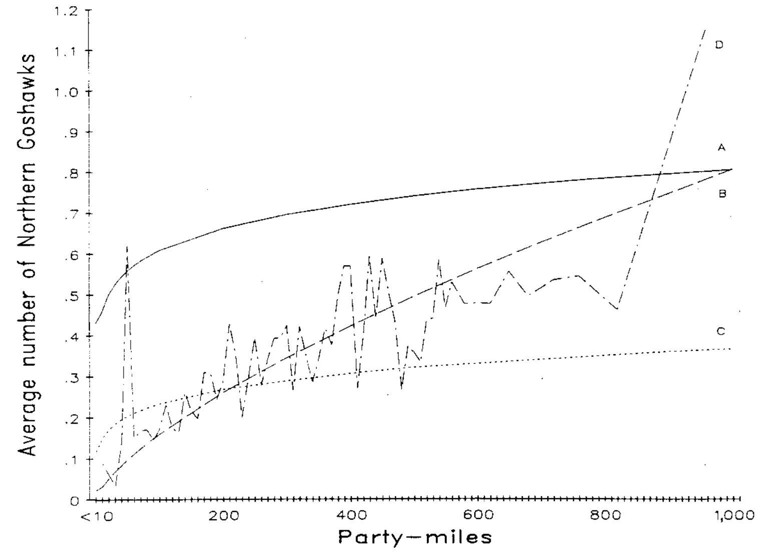


Fig. 7. Four ways to express the relation of count versus effort for the northern goshawk (*Accipiter gentilis*). *A* represents a log-log regression of count versus effort when a constant of 0.5 is added to all counts. *B* represents the nonlinear regression. *C* represents a log-log regression when 1/6 is added to all counts. *D* connects all the means of counts per 10-party-mile groups.

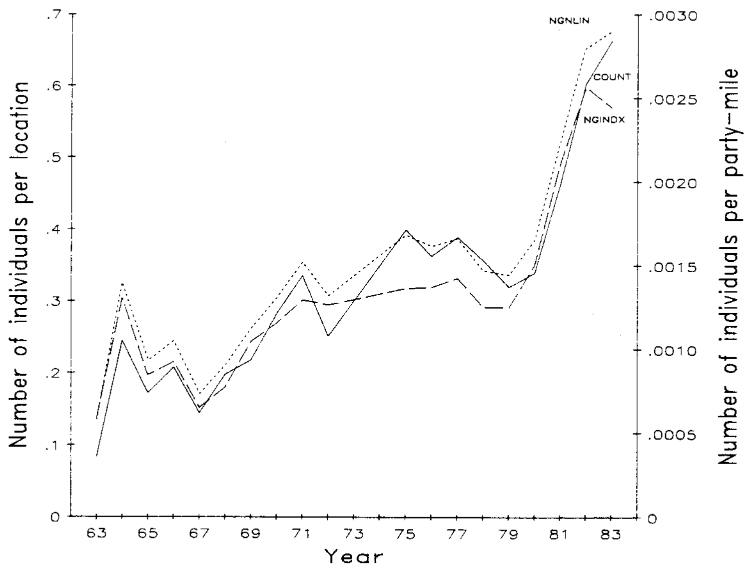


Fig. 8. Three indices of population levels for the northern goshawk (*Accipiter gentilis*). None of the three indices include any modifications for changes in the locations represented in different years. The high counts in the last 2 years represent major irruptions from more northern wintering areas. The *solid line* represents the relation as determined from the raw, unmodified counts (COUNT; using the scale on the left side of the figure). The *dotted line* connects data calculated from counts that were standardized using the nonlinear regression (NGNLIN; using the left scale). The *dashed line* represents population changes calculated from counts that were standardized by dividing the raw counts by party-miles (NGINDX; using the right scale).

effort (Fig. 9). Again, we feel that the nonlinear model provides a closer fit to the actual data than do the two log-log models; however, none of the models follow the sharp decline in count at very high values for party-hours. This decline may be an artifact of a correlation between high effort on CBC's and urban environments that may be unsuitable for black ducks (see Possible Relations Between Count and Effort). For black ducks, we calculated a population trend index by dividing a population estimate that used 3 years of data from the early 1980's (1979–80 through 1981–82) by a population estimate that used 3 years of data from the early 1950's (1949–50 through 1951–52). Using raw, unmodified counts, the black duck index was 41%. Using raw counts divided by party-hours, the index was 20%. Using standard counts as recommended earlier, the index was 28%.

For goshawks, the trend estimate from 1963 through 1983 is essentially the same no matter how the counts are treated (Fig. 8); however, for black ducks, there is a dramatic difference in the perceived severity of the decline from 1950 through 1983 depending on how the counts are modified (Fig. 10). The major reason differences in treatments did not affect our estimate of trends for the goshawk seems to be the large number of zeros for that species (6,900 of the 9,100 data points in the study). In most count areas, goshawk counts varied from zero to one (Fig. 11), and this change produced most of the noted changes in abundance. Modifications of these small numbers had little effect. On the other hand, some black duck counts were in the tens of thousands (Fig. 12). Modifications of these numbers had a large effect on our estimate of the population dynamics of black ducks.

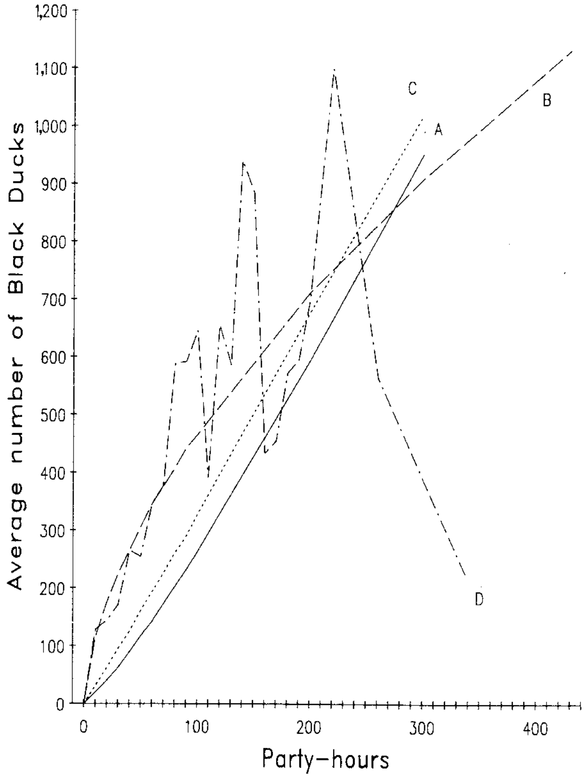


Fig. 9. Four ways to express the relation of count versus effort for the American black duck (*Anas rubripes*). *A* represents a log-log regression of count versus effort when a constant of 0.5 is added to all counts. *B* represents the nonlinear regression. *C* represents a log-log regression when 1/6 is added to all counts. *D* connects all the means of counts per 10-party-hour groups.

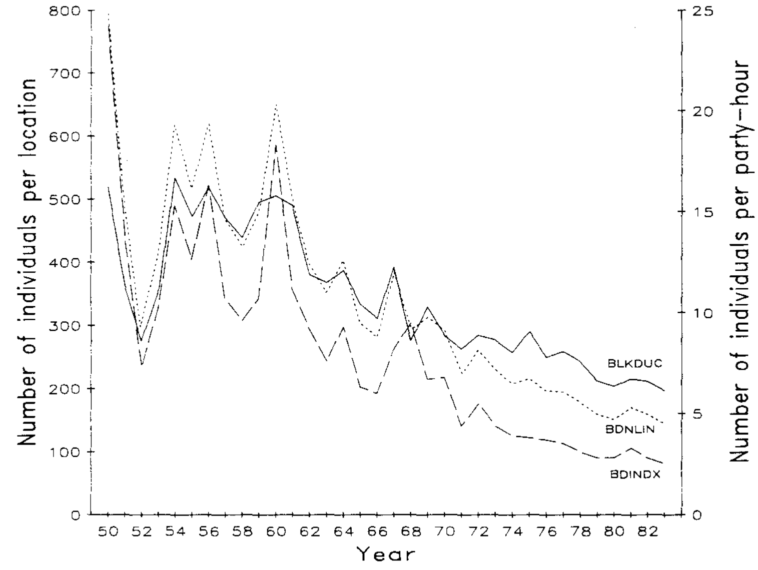


Fig. 10. Three indices of population levels for the American black duck (*Anas rubripes*). None of the three indices include any modifications for changes in the locations represented in different years. The *solid line* represents the relation as determined from the raw, unmodified counts (BLKDUC; using the scale on the left side of the figure). The *dotted line* connects data calculated from counts that were standardized using the nonlinear regression (BDNLIN; using the left scale). The *dashed line* represents population changes calculated from counts that were standardized by dividing the raw counts by party-miles (BDINDX; using the right scale).

Conclusions

1. Birds observed at bird feeders and birds observed at night should be reported and analyzed separately from birds observed during the day by moving parties.
2. Analysts should determine the empirical relation between count and effort to determine if counts need to be adjusted for effort.
3. Because effort on CBC's has increased with time, a year variable should be included when determining the relation between count and effort.
4. If counts increase with effort, then nonlinear regression should be used to estimate the slope of the relation between count and effort. Raw counts should be converted to standard counts that would be expected with standard effort.
5. After conversion (or a decision that conversion is unnecessary), standard counts can be used for any studies that compare relative abundance through time or space.

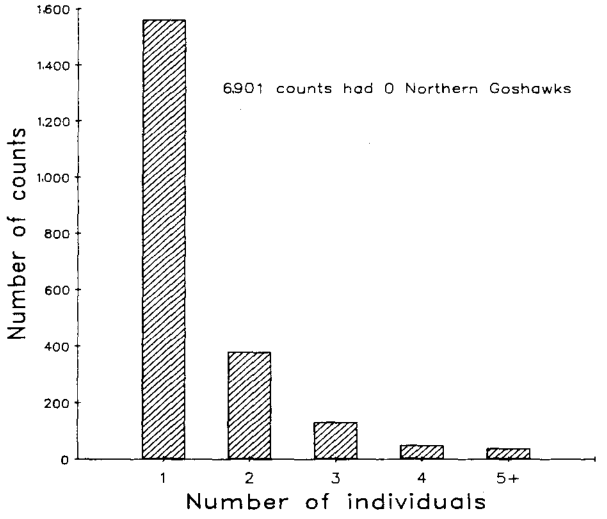


Fig. 11. Distribution of counts of northern goshawks (*Accipiter gentilis*; from 3 years in the early 1970's and 3 years in the early 1980's). The maximum count in these 6 years was 16.

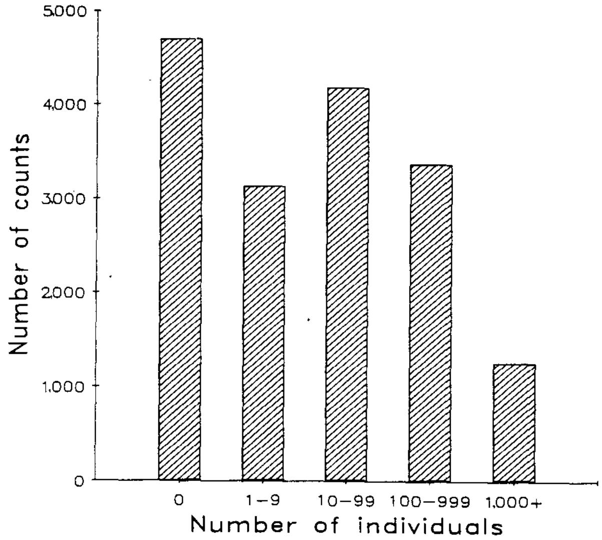


Fig. 12. Distribution of counts of American black ducks (*Anas rubripes*; during 1949-50 through 1981-82). The peak count during this period was 36,000.

Acknowledgments

The Christmas Bird Count Population Project at Cornell has been generously supported by J. KixMiller, G. W. Knight, N. B. Delavan Foundation, E. I. du Pont de Nemours and Company, Exxon Corporation, FMC Corporation, IBM Corporation, Johnson Foundation (Trust), MARS Inc., Merck Family Fund, Williams Companies Foundation, Inc., and many others. We thank J. Lowe for his extensive work with the CBC data and his preparation of the figures, and T. Engstrom, J. Sauer, and an anonymous reviewer who significantly improved the manuscript. In addition, we thank the many CBC volunteers who collected, recorded, and edited the data; National Audubon Society and staff of *American Birds*, who coordinate the CBC and publish the results; and C. E. Bock and J. Shipman, who provided us with computerized CBC data.

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Population Trends in the Least Tern (*Sterna antillarum*) from Maine to Virginia: 1975–1986

by

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ABSTRACT.—The least tern (*Sterna antillarum*) is endangered in 4 of the 10 coastal States from Maine through Virginia. We used data from the Colonial Bird Register to evaluate trends in the abundance of least terns from 1975 to 1986 for State populations and for the entire region.

The total number of breeding pairs of least terns recorded for the region increased during the study period from 6,740 in 1977 to 9,341 in 1986. Both 1977 and 1986 were years in which extensive counts were made in the region. Direct comparison of annual totals should be made with caution, because these totals can be influenced by which colonies are censused in a year. Only 132 of 311 colony sites were censused for 6 or more years during the study period.

The methods used to count terns varied among years and among colonies. Comparing aerial to ground counts was of particular concern because more aerial counts were done in the early part of the census period. We used correction factors to make aerial and ground counts comparable.

We used weighted regression to obtain an estimate of population change over the 12-year study period. The regional trend is a combination of the slopes of individual colonies weighted by colony size and an index of sampling effort. The regression analysis, originally developed to analyze Breeding Bird Survey data, can accommodate missing data for some years at some sites. The results of the regression analysis of the regional population of least terns indicated a 5.0% increase per year over the 12-year study period ($P = 0.10$), even though colonies with negative slopes outnumber colonies with positive slopes 166 to 106. Our results indicated that the weight for colony size contributes to the overall increase.

These results were encouraging, but the increases may have been caused in part by improved and expanded efforts to monitor the species rather than true population changes. The least tern deserves continued attention because its preferred breeding habitat, coastal sandy beaches, will continue to be subjected to heavy pressure from urbanization and human recreation.

Introduction

In the United States, the least tern (*Sterna antillarum*) usually nests in colonies along the Atlantic and Gulf coasts from Maine to Texas, on the California coast from San Francisco Bay southward, and in freshwater habitats from North Dakota to Texas (American Ornithologists' Union 1983; Carreker 1985). Least tern populations were severely depleted in Massachusetts (Nisbet 1973) and possibly eliminated from New York (Bull 1964) in the late 19th century by the millinery industry. After legal protection, the least tern has repopulated New York (Gochfeld 1973) and increased in other States where it was diminished. It also has extended its range into Maine (Drury 1973; Hunter 1975).

Although populations of the least tern in California and the interior United States have been declared endangered by the U.S. Fish and Wildlife Service (U.S. Department of the Interior 1973; U.S. Fish and Wildlife Service 1985), the eastern population is not classified as endangered, threatened, or of management concern (U.S. Fish and Wildlife Service 1987) by the Federal Government. The least tern has no special State classification in Connecticut, Delaware, and Virginia. However, the least tern is considered endangered in

Maine, New Hampshire, New York, and New Jersey, threatened in Rhode Island and Maryland, and a species of special concern in Massachusetts. No least tern colonies have been documented for New Hampshire during the study period, although adults have been sighted several times during the breeding season (Gavutis, in preparation).

Concerns over the threat of offshore oil drilling (Erwin 1979), the loss of breeding habitat caused by urbanization, and disturbance from human recreation (Gochfeld 1983; Kotliar and Burger 1986) have spurred considerable effort to obtain quantitative data on populations of least terns in the eastern United States (Gochfeld 1973; Duffy 1977; Buckley and Buckley 1980; Kress et al. 1983; Burger 1984; Spendelow and Patton 1988). Currently, least tern populations are monitored annually in many States (e.g., MacLean et al. 1988). Downing (1973) and Fisk (1975) reported on a cooperative survey of least terns along the Atlantic coast, but the first intensive systematic effort to count least terns occurred in 1977 as part of a survey and census of all coastal colonial waterbirds from Maine to Virginia (Erwin and Korschgen 1979).

The amount of concern by States suggested to us a need to examine trends in populations of least terns for the coastal States from Maine through Virginia. We analyzed trends for least terns in this region for the period 1975–86 using a weighted regression technique (Geissler and Noon 1981). We also examined the relation between regression slope, weighting factors, and sign of the regression slope for each colony.

Methods

The Colonial Bird Register Data Bank

In 1975, the Cornell Laboratory of Ornithology and the National Audubon Society jointly initiated the Colonial Bird Register (CBR). The CBR is a computerized bank of information on species composition and abundance in colonies of seabirds and wading birds (McCrimmon 1978). The colony location, date of visit to the colony, physical characteristics of the colony site, and census method also are recorded on standardized forms (Engstrom 1990). The survey and census of colonial waterbirds in the northeastern United States in 1977, coordinated by the U.S. Fish and Wildlife Service (Erwin and Korschgen 1979), constitutes the foundation of CBR data that were used in this study. Most CBR least tern data were contributed by organized efforts, such as the annual survey of Long Island colonial waterbirds (MacLean et al. 1988) and various State-sponsored surveys.

Definition of a Colony

Least terns may breed at different colony sites in different years (Nisbet 1973) or move to new sites if breeding is disrupted within a year; hence, it is difficult to define a colony. Short-distance relocations of colonies over years can result in a proliferation of colony names, especially when surveys are not centrally organized. We consulted with the observers who contributed data to the CBR to check colony site names, locations, and number of least terns. We used colonies as defined by contributors, although we pooled subcolonies as named by contributors in some cases.

Counts in Virginia were complicated. Instead of giving each colony site its own name, sites in a locality (usually an island) were given a number as they were encountered in a year. The number for the colony site one year may be used for a different site the next. For this reason, we pooled numbered colonies within localities, such as islands, for each year.

Estimation of the Number of Breeding Pairs

To make data comparable among colonies, we standardized all census results to the number of breeding pairs. Census results were reported to the CBR as the number of adults, the number of nests, or both on some CBR forms. If nests were counted, we assumed that the number of breeding pairs equalled the number of nests. However, a variety of correction factors have been proposed to convert the number of adults observed in a colony area into an estimate of the number of breeding pairs. We were especially concerned about the correction factor for estimating the number of pairs from aerial counts of adults, because aerial counts were done more frequently in the early part of our study period. Underestimating the number of pairs from aerial estimates in the early years would bias trends upward.

In the U.S. Fish and Wildlife Service survey and census of colonial waterbird colonies in the coastal northeastern United States in 1977 (Erwin and Korschgen 1979), aerial counts of least terns were considered to be equivalent to the number of breeding pairs based on a regression of aerial estimates of adults versus the number of nests (Erwin 1979:49). Buckley and Buckley (1980) and Duffy (1977) used a correction factor of 0.9 to convert counts of adults to the number of breeding pairs. Thompson (1982), after an intensive study, suggested a correction factor of 0.6 for the least terns along the coast of Texas (adult count × 0.6 = number of pairs).

In our analysis, if aerial techniques were used to census a colony, we assumed a 1:1 ratio for the number of adults and the number of breeding pairs (Erwin's 1.0

correction factor) and used records from May and June only to eliminate possible prebreeding aggregations or late-season colony relocations. For ground counts of adults, we multiplied the number of adults seen by a correction factor of 0.5. We felt that this was a conservative estimate of the number of pairs. If a nest count and an adult count were provided on the same form, we used the larger of the two estimates.

Trend Analysis

We used a weighted linear regression procedure (Geissler and Noon 1981) to estimate population trends for the least tern from 1975 to 1986. The strength of the Geissler and Noon (1981) weighted regression method, designed specifically to estimate trends for Breeding Bird Survey data, is that it can be used even when data are not available for some locations in some years. For example, the number of values used in a regression for a colony in this study is between 2 and 12. The technique distinguishes between zeros and missing values. This is especially important when coverage is uneven among years.

This procedure includes the following steps. The estimated number of breeding pairs in a colony for a year, plus a constant of 1.0 to adjust for zeros, is transformed to its logarithm. The number of pairs is regressed against year for each colony having 2 years or more of data, using linear regression (GLM procedure; SAS Institute Inc. 1982). The individual colony regression slopes were back-transformed, then combined to estimate a trend for each State and for the northeastern region as a whole using

$$t = \sum b_r w_r \,/ \sum w_r \qquad (1)$$

where

t = estimated trend on logarithmic scale for a State or region,
b_r = estimated trend for *r*th colony on logarithmic scale [ln(*b*)], and
w_r = weight for the *r*th colony.

Before combining the regression values, they were weighted according to the geometric mean of the number of breeding pairs at each colony for all years,

$$\left[\Pi_y (C_y + 1.0)\right]^{1/p} - 1.0, \qquad (2)$$

where

C_y = the count for the *r* th colony in the *y*th year and there are *p* annual counts and an index of sampling effort (the sample variance of the observed years)

$$\left[(n-1)\sum_n (y-\bar{y})^2\right]^{0.5} \qquad (3)$$

where

n = the number of years when counts were made,
y = the year (Geissler and Noon 1981; Robbins et al. 1986).

Ninety percent, 95%, and 99% confidence intervals were calculated for the State and regional trends by bootstrap replications.

Results

Coverage, Colony Size, and Geographic Distribution

In the study region, the consistency of count effort for least tern colony sites varied among States and years (Table 1; Fig. 1). For example, 8 of 10 colony sites in Maine were surveyed for 10 years from 1977 to 1986, but in Maryland, 20 colony sites were censused for 3.2 years on average during the 12-year period, and only 2 of the colonies were censused for 6 years or more. The most complete counts of least terns were conducted in 1977 and from 1982 to 1986 (Table 2) in most States. In all States combined, 42% of all colonies (132/311) were censused for 6 years or more during the study period.

For all colonies over all years, colony size ranged from 1 to 850 breeding pairs, with a median of 25 pairs (n = 1307). This median colony size may be slightly biased upward because large colonies tended to be censused more frequently than small colonies in some years. The median colony size ranged from 19 to 30 pairs per colony among years (Table 3). In the 1984 survey, New York reported the largest number of breeding pairs of least terns of all States in the region (Table 3; Fig. 2).

The annual total of breeding pairs indicates an increase from 1977 to 1986 from 6,740 to 9,341 (Table 3), when efforts to visit all colony sites were comparable. Note that more colonies were censused by air in 1977 than in 1986.

Linear Trends

The rate of change in the regional population of least terns, as estimated by the Geissler and Noon (1981) weighted regression, is a 5.0% per year increase (P = 0.10; Table 4). The overall trend is a 74% increase over the 12-year period (P = 0.10). In trends for individual States, Virginia (P = 0.05; 9.7% per

Table 1. *The consistency of censusing effort for the least tern (Sterna antillarum) by State during 1975–86 for records in the Colonial Bird Register (CBR). This includes colony sites where no terns were found.*

State	Total number of colonies	Number of census years per colony[a]	The number of colonies censused ≥ 6 years
Maine	10	8.1	8
Massachusetts	75	5.8	35
Rhode Island	13	5.8	8
Connecticut	13	6.1	6
New York	93	4.9	34
New Jersey	49	5.3	19
Delaware	15	4.3	10
Maryland	20	3.2	2
Virginia	23	5.6	10
Total	311	5.2	132

[a] The total number of censuses of all colonies for the 12-year period divided by the total number of colonies.

year) and Rhode Island ($P = 0.10$; 18.6% per year; Table 4) showed positive trends significantly different from zero. Maryland was the only State that had a negative regression slope ($P = 0.05$; −12.2% per year).

The negative regression slope for Maryland (Table 4) seems to be contradicted by an apparent increase indicated by the changes in the annual total number of terns counted (Table 3). This contradiction was caused by the uneven coverage during the study period (Tables 1 and 2). The most thorough coverage in Maryland occurred in 1985 and 1986, when more than twice as many colony sites were censused than during any of the previous 10 years. The annual totals in Maryland were influenced by which colonies were censused in a particular year.

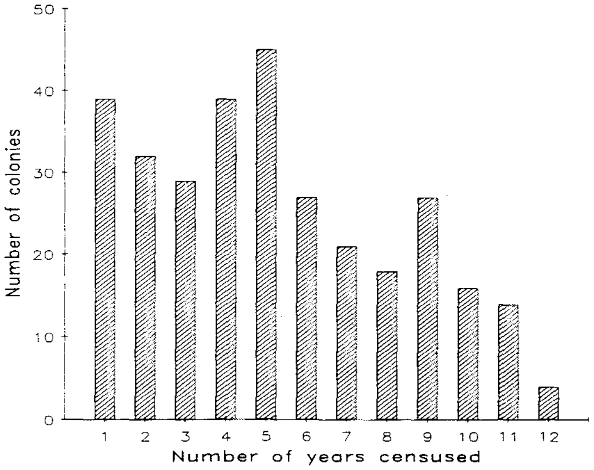

Fig. 1. The number of colonies and the classes of census-years ($n = 311$). The 39 colonies that were only censused for 1 year during the study period were omitted from the regression analysis.

Analysis of Weighting Factors

Colonies with negative regression slopes outnumber colonies with positive regression slopes in seven of nine States (Table 5). The overall ratio of negative to positive slopes is 1.6:1 ($n = 272$). This result seems to be the opposite of what one would expect with the positive regional trend of 5.0% per year. Three factors affect the regional trend: regression slopes, weights for colony size (the geometric mean of counts over all years), and weights for the index of sampling effort (sample variance of the observed years). We analyzed these factors by dividing the colonies into two groups: those with positive slopes and those with negative slopes.

The absolute values of slopes of decreasing colonies (negative slopes) are significantly larger than slopes of increasing colonies (Mann-Whitney test; $P = 0.06$). Therefore, the magnitude of the slopes does not contribute to the observed positive slope for the region. The index of sampling effort also is not significantly different between increasing and decreasing colonies (Mann-Whitney test; $P = 0.52$). However, size weights for colonies with positive slopes are significantly larger than the weights given to colonies with negative slopes (Mann-Whitney test; $P = 0.0003$; Table 5) and larger colonies are given more weight in the regression; therefore, the overall trend is positive.

Table 2. *The number of colonies of least terns (*Sterna antillarum*) included in the Colonial Bird Register by State by year. Survey effort varies substantially among States among years; therefore, the annual totals should be compared with caution.*

	Year											
State	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Maine			8	7	7	8	8	8	8	8	9	10
Massachusetts	10	32	44	34	40	38	36	36	34	48	43	40
Rhode Island		6	7			1	7	11	11	12	12	12
Connecticut	4	6	7			9	3	7	8	12	9	10
New York	9	27	40	1	26	4	6	67	69	83	78	45
New Jersey		25	28	34	29	24	21	18	23	22	10	14
Delaware	1	1	5	6	7	8	7	7	7	3	5	7
Maryland	1	1	5	4	6	1	3	4	2	6	16	15
Virginia		16	21	12	12	10	10	11	10	11	8	7
Total number of colonies	25	114	165	98	127	103	101	169	172	205	190	160

Table 3. *The number of breeding pairs of least terns (*Sterna antillarum*) included in the Colonial Bird Register by State by year. Survey effort varies substantially among States among years; therefore, the annual totals should be compared with caution.*

	Year											
State	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Maine			65	88	70	70	95	39	63	88	105	124
Massachusetts	511	1,354	1,527	1,434	2,009	2,040	1,856	1,812	2,199	2,400	2,321	2,245
Rhode Island		18	45			0	87	237	248	162	146	127
Connecticut	134	169	121			127	155	426	172	372	820	1,108
New York	266	913	2,136	120	1,439	540	412	1,447	2,126	2,742	2,462	2,911
New Jersey		740	1,277	1,296	1,035	1,057	1,028	1,230	1,160	1,122	679	1,079
Delaware	0	50	148	495	721	560	717	780	600	362	496	480
Maryland	112	4	212	273	269	1	61	207	135	556	718	553
Virginia		858	1,209	136	206	398	934	293	1,104	966	378	714
Total number of breeding pairs	1,023	4,106	6,740	3,842	5,749	4,793	5,345	6,471	7,807	8,770	8,125	9,341
Median colony size	25	19	30	26	29	30	27	28	27	23	24	30

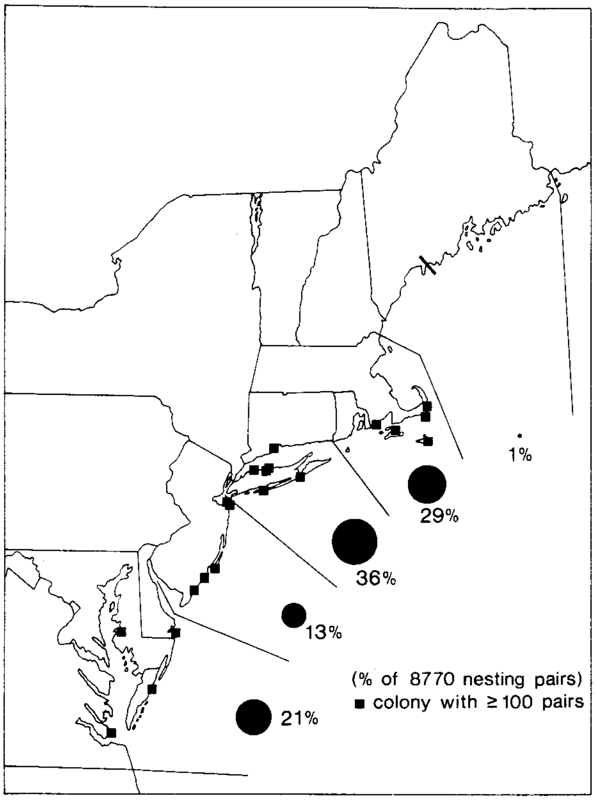

Fig. 2. The percentage of least tern colonies in regions of the northeastern United States as calculated from 1984 CBR data. The squares along the coast mark colonies that contained 100 or more pairs of least terns in 1984. The black line in Maine represents the northern limit of breeding least terns.

Discussion

Monitoring Least Terns

Least terns are difficult to count (Nisbet 1973) because they may shift colony sites within a season and among seasons. Faithfulness to nesting sites, however, may be common as long as the sites remain undisturbed (Gochfeld 1983; Burger 1984; Atwood and Massey 1988). Regardless of the difficulties, the species should be monitored within a well-organized regional program for the following reasons: (1) the least tern is considered either threatened or endangered by most of the coastal States from Maine to Virginia; (2) least tern colony instability makes surveys over large areas especially important; and (3) much of the breeding habitat of least terns along the Atlantic coastline is under extreme pressure from human population growth (Parnell et al. 1988).

Several elements are essential to develop a system for monitoring least terns. First, standard counting methods need to be established and used consistently over time (Drury 1980). Second, a working definition of a colony needs to be adopted and regularly employed. Third, the best time of the year for counts should be defined for different regions, although this may vary somewhat from year to year. Finally, census techniques and data management should be coordinated among States to ensure that results will be comparable and compatible. Programs of individual States that entail cooperation among professionals and volunteers, such as the Long Island Colonial Waterbird Survey (MacLean et al. 1988), could be the foundation for a broader regional or national monitoring effort.

Correction factors strongly affect the results. The difference between the 1,786 pairs of least terns in New Jersey in 1977 (Erwin and Korschgen 1979), 942 individuals (Kane and Farrar 1977; Burger 1984), and 1,277 pairs (our results; Table 3) were caused by different correction factors used for ground and aerial counts for the same primary data.

A variety of counting techniques were used to collect CBR data for the least tern. Different levels of precision and biases associated with the various techniques could invalidate the use of CBR data for trend analysis (Erwin 1980). For this reason, we tried to correct for systematic biases that might affect trend analysis. For example, we have pointed out that counts were made from the air more frequently in 1977 than in later years. This could potentially bias the trend upward if aerial counts tend to be underestimates. To adjust for this potential bias, we converted numbers of individuals into numbers of pairs with a correction factor; however, it's possible that this factor may not fully compensate for birds missed from the air. If so, at least some of the reported increase in least terns may be an artifact of the more complete ground counts in the latter part of the study.

Population Trends

According to our analysis of CBR data, regression slopes are positive for least tern populations in every State in the region except for Maryland, although only the positive trends in Rhode Island and Virginia are significantly different from zero (Table 4). The regional population shows a statistically significant 5.0% increase per year ($P = 0.10$). Increases in least terns have been reported recently in other studies in New York (Gochfeld 1973; Buckley and Buckley 1980) and New Jersey (Burger 1984): the States having the first and third highest number of least terns in the study region (Table 3).

The support from other studies strengthens our conclusion that least terns have increased in the study

Table 4. *Population trends estimated with the Geissler and Noon (1981) weighted regression model for the least tern (*Sterna antillarum*) from 1975 to 1986. The trends are expressed as percentage change. Confidence levels are: * = 90% and ** = 95%.*

State	Number of colonies[a]	Change per year (%)	Change (1975–86) (%)
Maine	9	2.9	37
Massachusetts	63	1.7	21
Rhode Island	13	18.6*	554*
Connecticut	12	6.5	100
New York	87	3.5	46
New Jersey	43	4.5	63
Delaware	9	4.3	58
Maryland	18	−12.2**	−76**
Virginia	18	9.7**	178**
Total	272	5.0*	74*

[a] The number of colonies with ≥ 2 years of data.

region. Of course, the results of any regression analysis will depend on which years are included. When we started this project, we analyzed only 10 years (1975–84) of CBR data for the region. The results of this initial analysis showed a nonsignificant increase ($P > 0.10$; 3.7% per year; 43% for the 10-year period). The sharp increase from 1985 to 1986 probably tipped the increase detected by regression to weak statistical significance.

When a population is likely to vary widely among years, we may want more than a single trend value to characterize changes within population over 12 years. Annual indices show year-to-year population variability and are an important supplement to the overall population trend. Unfortunately, reliable annual indices were not available for this study. Graphical techniques to display annual changes or longer trends in relation to geographical location and the pattern of abundance would be desirable. For example, it might be possible to superimpose over a map of a region, shades of color indicating population change and a three-dimensional contour of abundance. This type of exploratory analysis would help researchers to define regions of rapid change without having to rely on preëstablished groupings of the data.

We analyzed the components of the estimated trend (slope, geometric mean of colony size, and the index of

Table 5. *Median of the geometric means of least tern (*Sterna antillarum*) colonies having positive and negative regression slopes from 1975 to 1986.*

	Colonies with positive slope		Colonies with negative slope	
State	Median	*N*	Median	*N*
Maine	17.9	3	1.2	6
Massachusetts	21.0	29	15.3	34
Connecticut	12.4	5	2.6[a]	7
Rhode Island	4.5	7	2.0	6
New York	10.3	40	5.2[a]	47
New Jersey	72.3	8	3.9[a]	35
Delaware	121.8	2	25.0	7
Maryland	51.9	3	6.0	15
Virginia	24.3	9	21.1	9
Region	14.9	106	6.9[a]	166

[a] Significant at $P < 0.05$ in the Mann-Whitney test.

sampling effort) to assess how the components might have affected the trend. The result that colonies having positive slopes were significantly larger than those having negative slopes (Table 5) indicated that changes in larger colonies controlled the regional trend. This result has management implications for the least tern, if smaller colonies are consolidating into larger colonies, as suggested by Burger (1984) for New Jersey. Concentration of the population into larger colonies at fewer sites could make the population more susceptible to catastrophe.

Identifying biological factors that are causing the positive trend in the population over a 12-year period is beyond the scope of this study. Increases in immigration, productivity, and overwinter survival could all contribute to the trend. Our data do not provide a direct index of productivity. However, we feel that our analysis showed that the population of least terns from Maine to Virginia is increasing as indicated by the results of the weighted regression analysis and the increase in total numbers of breeding pairs from 1977 to the period 1982–86, when efforts were made to survey all colonies of least terns.

While this result is encouraging, the recent success of least terns may be attributable to the amount of management effort expended in recent years (Jackson and Jackson 1985; Kotliar and Burger 1986). Like the endangered piping plover (*Charadrius melodus*), the least tern deserves sustained attention because the coastal beaches they require for nesting will continue to be used heavily for human recreation and development.

Acknowledgments

We thank the many people who took the time to count least terns and to fill in CBR data forms. Our principal contacts by State were: R. M. Duclos, F. Sibley, and J. Zickefoose (Connecticut); P. Jahn and J. Thomas (Delaware); J. Arbuckle and A. Hutchinson (Maine); D. Brinker and J. McKearnan (Maryland); B. Blodget, R. Forster, and T. French (Massachusetts); D. Jenkins (New Jersey); T. Litwin, D. MacLean, D. Petersen, and M. Scheibel (New York); C. Raithel (Rhode Island); B. Williams and K. Terwilliger (Virginia).

We thank the staff of Bird Population Studies at the Cornell Laboratory of Ornithology, especially S. Sutcliffe, and the many students and volunteers, E. Bachman in particular, who have coded data into the computer and double-checked colony names. J. L. Atwood, E. H. Burtt, Jr., R. M. Erwin, J. M. Hagen, S. W. Kress, R. J. O'Connor, C. R. Smith, and J. A. Spendelow made many useful comments on the manuscript.

This report was funded in part by the U.S. Fish and Wildlife Service under Cooperative Agreement Number 14-16-0009-85-957.

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Trend Analyses for Raptor Nesting Productivity: An example with Peregrine Falcon Data

by

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ABSTRACT.—Reproductive data can be used in determining the status of raptors and setting research and management priorities. Many surveys to find raptor nests or to assess raptor reproduction are conducted by government agencies, groups, and individuals. Survey methods include a variety of field procedures that often are not standardized or based on a statistical design. Appropriate analytical methods need to be identified or developed for these surveys. In this paper, we describe statistical methods used to explore the suitability of data gathered during a raptor nest survey for estimating trends in productivity.

Introduction

Data from surveys of peregrine falcons (*Falco peregrinus*) in west-central Greenland during 1972–85 (Mattox and Seegar 1988) were examined to assess temporal changes in peregrine productivity. The measure of productivity in a given year was the number of banding-age young (about 3 weeks old) per nest. Several features of the survey make it difficult to identify appropriate analyses: some sites (cliffs) at which nesting occurred in earlier years were not checked every year; more search effort was invested in later years; nest searches were concentrated in the best peregrine habitat and in a core study area; and most sites were included in the data set only after being found occupied. An occupied nest was inhabited by a single peregrine or a pair. These survey characteristics are not uncommon for other peregrine surveys or those for other raptor species (Fuller and Mosher 1981; Cade et al. 1988). We examined several different methods for analyzing these nest survey data.

Methods

Trend Analysis

We used variations of the route-regression method (Geissler 1984) to estimate production trends. This method makes comparisons only among observations made on the same nest sites in different years, minimizing the adverse effects of not checking some sites every year and of concentrating effort on the best habitat and in the later years. For example, analyzing the total observed productivity would show an increase simply because more nests were checked in later years. The route-regression method estimates the variance among sites instead of among years. The variance must be estimated among nest sites because nest sites are the sampling units, and production in successive years is not independent.

The route regression method uses a linear regression to estimate the rate of change (trend) in productivity for each nest site. The nest site is analogous to the survey route in Geissler (1984). These nest-regressions are used to predict the production in the middle year of the sampling period and the year after the middle year, assuming the average rate of change for each site over the period investigated occurred between these years. These predicted productions are summed over nest sites

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to estimate the total production in each of those years. The production trend is then estimated as the ratio of the total production in the year after the midyear to the total production in the midyear. That ratio estimates the average annual change in productivity for the population during the period of interest.

We used two route-regression methods to estimate the average change (trend) for a nest site. An additive linear regression estimates the rate of change in terms of the number of young fledged per year, using the slope of an ordinary linear regression. A multiplicative model estimates the percent change per year using a linear regression and log transformation of the number of young produced:

$$y = ab^{X}e$$

where y = number of young produced, X = year, e = error term, a = intercept, and b = trend. Using logarithms, this model becomes a linear regression:

$$\ln(y + 0.5) = \ln(a) + \ln(b)X + \ln(e).$$

Both route-regression methods can be fit by the ordinary least squares approach or the Theil nonparametric method (see Hollander and Wolfe 1973:209). Theil's method uses the median of the trend estimates calculated for every possible pair of years. Although use of the median minimizes the effect of a few discordant observations, it inhibits detection of a sharp change in productivity.

Paired-t Comparisons

Paired t-tests were used to compare characteristics within individual nest sites. We tested for changes in the population after the ban of DDT in 1972. Peregrines are long-lived and usually do not breed until they are more than 2 years old (Newton and Mearns 1988). The year in which effects of the DDT ban might be apparent is unknown; therefore, we compared two arbitrary groupings of the data. The period from 1972 to 1978 was compared with that from 1979 to 1985, and the period from 1972 to 1979 was compared with that from 1980 to 1985. Groups of years within the 14-year survey included only nest cliffs known in both periods. For each group, paired t-tests were conducted using nests as observations with the following variables: (1) number of young produced (banded) for all productive nest sites; (2) number of young produced for all sites with peregrine pairs; (3) number of young produced for all nest sites occupied by a peregrine; and (4) number produced for all nest cliffs surveyed in both periods.

Analysis of Variance

We used analysis of variance to assess whether some years or nests were consistently more productive than others. Years were crossed with nests and the interaction was used as the error term. Analyses were conducted for nests occupied by peregrines, nests checked, and productive nests. The dependent variable was the number of banding-age young per nest.

Results

None of the trend analyses yielded significant results ($P > 0.05$; Table 1). Paired-t comparisons between 1972–78 and 1979–85 indicated a significant increase between periods of 0.58 birds per nest ($P < 0.05$), based on the number of young produced in all nests that were checked. Paired-t comparisons between 1972 and 1979 and 1980–85 showed significant increases ($P < 0.05$) of 0.57 birds per nest for the number of young produced in all productive nests, 0.70 birds per nest for the number of young produced in all nests with adult pairs, and 0.64 birds per nest for the number of young produced in all checked nest sites.

Some nest cliffs were consistently more productive than others, based on analysis of variance ($P < 0.01$). However, tests using analysis of variance showed no significant relation between years and numbers of banding-age young per nest.

Discussion

Testing for changes in productivity of raptor nests can be approached in several ways. Trend analysis can be used to estimate the average rate of production change over the whole period. Alternatively, one can use a paired t-test to determine if the mean production in individual nests is the same in different periods. The trend analysis and the paired t-test use nest sites as independent replicates. Years are not independent because the same peregrines might return to the same nest site for several years (Ambrose and Riddle 1988; Mattox and Seegar 1988; Newton and Mearns 1988), and their decision to return might be influenced by their success the previous year. An analysis of variance tests the more general null hypothesis that there are no differences among years, but requires the more restrictive assumption that both years and sites are independent. If they are not independent, the interaction term (assumed to be zero) will inflate the error term, making the tests conservative. Consequently, our analysis of variance indicated no significant changes when, in fact, changes might have occurred. Together, these tests and estimates provide a comprehensive picture of changes through time.

Table 1. *Results of route regression methods to test for trends in productivity at peregrine (*Falco peregrinus*) nests in western Greenland.*

	Mean annual change	Significance	d.o.f.	Standard error	95% C.I.
Multiplicative model (% change per year)					
Parametric trend analysis					
Productivity per occupied nest	2.69	n.s.	22	3.3	–3.2, 9.5
Productivity per productive nest	1.33	n.s.	22	1.0	–0.4, 3.3
Non-parametric trend analysis					
Productivity per occupied nest	–3.99	n.s.	21	4.6	–12.1, 5.9
Productivity per productive nest	–4.45	n.s.	18	3.0	–10.6, 1.2
Additive model (nestlings per year)					
Parametric trend analysis					
Productivity per occupied nest	0.040	n.s.	22	0.06	–0.1, 0.1
Productivity per productive nest	0.047	n.s.	22	0.03	0.0, 0.1

Either an additive or a multiplicative model can be used to estimate production trends with the route-regression technique. Multiplicative models often are used to estimate population trends because the population in one year is likely to be a multiple of the population in the previous year, due to the multiplicative effects of birth and death. Thus the annual increase or decrease is expressed as a percentage of the current population. However, production is not likely to be a multiple of the previous year's production at the same nest because production depends more on external factors than on previous productivity. Consequently, an additive model, expressing the annual increase in terms of the number of young produced per year, should be more appropriate.

The nest search procedures for most North American peregrine surveys (Cade et al. 1988:27–121) make the trend estimates difficult to interpret. Usually a nest site is identified as such only after it is first determined to be occupied by birds. After a site has been identified, it is usually checked each year, and biologists can easily document the abandonment of a nest site, thus biasing estimates towards decreases. When a potential nest site is found, it often is difficult to determine if the site was previously occupied. Thus most nest site records start with an occupied nest. To minimize this bias, we did not use the record for the year a nest site was identified, so the records for a site could start with either an occupied or an unoccupied nest.

The increasing search effort in the recent years of the Greenland Peregrine Falcon Survey (Mattox and Seegar 1988) complicates the study of trends. With the trend analysis, a separate trend is estimated for each nest site. If many nest sites have observations only for the last few years, the trends will disproportionately reflect changes that occurred in later years. This effect is counteracted by the route regression method, in which each nest site is weighted by the amount of information available (inverse of the relative variance). Initially, many nests were discovered because they were near the base camp at Sondre Stromfjord. These nests were checked more consistently because they were known and easier to reach. The influence of these nests also is increased by the weighting. An unweighted analysis would give all nests equal influence and would emphasize the trends in later years. One cannot simultaneously adjust for both time and location biases. We chose to use a weighted analysis adjusting for time biases.

Conclusions

These peregrine nest production data were difficult to interpret because of sampling biases. We have discussed ways of minimizing the effects of these biases and provided estimates of the change in production over time. Field procedures also should be modified to minimize future biases, although some problems remain because of the difficult terrain. The need for random sampling of nest sites cannot be overemphasized.

Route-regression analysis seems suitable for testing changes in data gathered by the procedures used in raptor nest surveys such as the Greenland Peregrine Falcon Survey. The route regression with weighted analysis that adjusts for time, provides some consideration for the survey results that include more data in recent years. Also, we believe the additive model is more appropriate than the multiplicative one, to test for trends in productivity or yearly occupancy.

If there is concern about the accuracy of the observations, Theil's regression could be used instead of the ordinary least squares regression, in effect, reducing the influence of aberrant points. However, if these points are correct, discarding them makes the estimates insensitive to abrupt changes in production. For that reason, robust regressions such as Theil's probably should not be used for monitoring trends. The wildlife manager might better use the parametric method of least squares and risk falsely concluding that a change has occurred (type I error) rather than missing an actual change (particularly in a declining population) because a conservative test was used (e.g., Theil's).

If managers might err on the side of concluding that a change has occurred, the additional tests we conducted can be used to further evaluate possible changes. Like route-regression results, ANOVA results suggested no change among years. However, the paired *t*-tests indicated an increase in the number of nestlings per nest, based on all nests during the 1979–85 and the 1980–85 periods. Additional increases were suggested (e.g., more nestlings per productive nests) for the 1980–85 period. Biologists might conclude, from all the tests, that while there probably has been little change in the entire 14-year survey data, it is possible that in the most recent years an increase in the average number of nestlings per nest has occurred.

Acknowledgments

We thank W. G. Mattox and W. S. Seegar for providing data and information about the Greenland Peregrine Falcon Survey. W. S. Seegar and F. P. Ward provided support for our analyses. We thank J. Hatfield, J. R. Sauer, and K. Titus for reviewing our manuscript.

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Current Thinking on United Kingdom Bird Monitoring

by

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ABSTRACT.—This paper describes current thinking about the monitoring of landbird populations in Britain. It is based on recent reviews conducted by the British Trust for Ornithology (BTO) reappraising the purposes and cost effectiveness of its monitoring programs, particularly the Common Birds Census (CBC) and its analogues. In practice, monitoring has not been an operational objective of the Common Birds Census, largely because of the difficulties of interpreting the meaning of a single annual change in the population of a common species and because of incomplete habitat surveillance, particularly affecting scarce species. In addition, the absence of a stratified design for these schemes has prevented the use of their results as a national index. Financial limits prevent expansion of the Common Birds Census to meet these difficulties. Despite these problems, the results have proved useful in documenting the effect of habitat modifications on bird populations within significant habitats in Britain, particularly in the case of agricultural intensification and its effects.

The practice of using a simple annual index of population change for each species and of chaining these estimates over time, rather than resorting to an optimized statistical treatment of the data, has made the results accessible to a wider audience and user base than would otherwise have been the case. Even so, there is a case for strengthening the power of the available samples by using more sophisticated analysis, with the Mountford (1982) technique, in particular, a prime candidate for routine use. Homogeneity tests available with this approach would also help control drift in sample composition, the risks of which have increased in recent years with dwindling participation in the Census.

The BTO is experimenting with some new census techniques, particularly with a Constant Effort Sites scheme based on standardized banding effort. This scheme offers the promise of yielding productivity data not available with the CBC but tests of the validity of assumptions made with this method have not yet been published. The routine monitoring of the abundance of scarce species remains problematical, but the BTO's use of single species surveys offers a practical approach. The integration of these schemes is discussed.

The usefulness of various products currently available from the BTO's monitoring program is reviewed. The availability of adequate habitat data is particularly limiting, as is the high cost of manual processing of census maps. The strengths and weaknesses of the various types of analysis of monitoring data developed in Britain are evaluated and contrasted with North American practices.

Introduction

Perceptions of the role of bird monitoring programs in Great Britain have changed substantially over the last decade, partly because of funding requirements and partly because progress in the computerization of existing data has allowed new research and promoted recognition of new information needs. Here I review the thinking behind these changes. The emphasis throughout this paper is on current thinking about, rather than on factual description of, United Kingdom bird monitoring. The intention is to set out for North American readers the rationale behind the changes that have occurred in the light of nearly 30 years of United Kingdom experience. Differences in culture, attitudes, and local circumstances between North America and Britain limit the extent to which I can identify the relevance of this experience to the former, and I leave it largely to the reader to recognize such points. One might note in passing that there exists scope for an analogous paper in a British journal, to set out North American experience that could usefully be adapted to United Kingdom schemes. Examples of such points include the greater attention paid to statistical design of sampling and the reliance on refereed publication of methodological checks to promote the corresponding rigor.

The Common Birds Census (CBC) is the British Trust for Ornithology's (BTO) principal bird monitoring program and is described elsewhere in this volume. The BTO's Waterways Bird Survey (WBS) is effectively a linear CBC conducted along rivers, streams, and canals and is treated here as synonymous with the CBC. It is described in more detail in papers by Marchant (1980), Marchant and Hyde (1980), and Taylor (1983a, 1986). The CBC has been the subject of a number of technical reviews in recent years (Milner and Hornby 1977; O'Connor and Marchant 1981; O'Connor and Fuller 1984). These reviews have differed somewhat in their purpose, the first two being concerned principally with technical aspects of the CBC scheme, while the third also considered policy issues associated with the scheme. As a result of these reviews, the BTO has revised some aspects of the CBC scheme and has initiated exploratory work on other methods of bird monitoring. This paper summarizes the resultant thinking in relation to the monitoring of landbird populations in Britain. The monitoring of shorebirds and wildfowl is explicitly excluded from consideration. Details of the major schemes associated with these groups can be found in Prater (1981) and in Owen et al. (1986), and in the annual reports of the Birds of Estuaries Enquiry and the National Wildfowl Counts. Certain other United Kingdom monitoring schemes are reviewed in O'Connor (1985b).

A companion paper (O'Connor 1990) described a number of shortcomings of the CBC scheme as recently practiced in Britain. Several of these problems seem set to disappear if the most recent CBC instructions are rigorously enforced. Changes of particular importance in the latest revision are the re-definition of target habitats, increased emphasis on the problems that arise if the guidelines are breached, increased standardization of the recording requirements for difficult species, and more detailed guidance as to the habitat recording required. In addition, the revised rules expressly prohibit the use of tape recorded birdsong as an aid to censusing. The main differences between the current CBC rules and those of the International Bird Census Committee (IBCC) are noted by Marchant (1985). I assume here, unless critical to do otherwise, that the revised rules will achieve their intended purpose.

Objectives in Monitoring

Studying Population Trends

The CBC was started with the intention of providing an early warning monitoring scheme in relation to environmental changes in Britain. Changes in the level of bird populations can, in principle, reflect environmental changes in either the wintering grounds or the breeding grounds. Thus, Winstanley et al. (1974) found a correlation between a decline in the late 1960's in the numbers of whitethroats (*Sylvia communis*) breeding in Britain and a drought-induced reduction in the extent of this species' wintering habitat in the Sahelian Zone of Africa. Similarly, the use of persistent organochlorine agrochemicals during the 1950's was reflected in declines in the numbers of such species as peregrine (*Falco peregrinus*), sparrowhawk (*Accipiter nisus*) and stock dove (*Columba oenas*), and the subsequent introduction of controls on the use of these chemicals was accompanied by a recovery in the numbers of these birds (Ratcliffe 1980; O'Connor and Mead 1984; Newton 1986). More recently, the intensive management of agricultural land in Britain, particularly on arable crops, has been accompanied by regional decreases in the numbers of a variety of species (O'Connor and Shrubb 1986a; Potts 1986). On the other hand, population levels have also reflected changes naturally associated with weather or climate (Williamson 1975a; Jarvinen and Vaisanen 1977a, 1977b) and within the normal ability of bird populations for recovery. Not all population changes, therefore, constitute cause for concern.

The CBC results have, in practice, hardly been used for explicit monitoring. Two factors contribute to this. First, because the scheme focuses on common birds that are neither threatened nor harvested, the results do not form the basis for routine management action. In this the scheme's results differ critically from, say, the monitoring of wildfowl harvests in the United States and Canada. Second, the body of knowledge needed to interpret the meaning of the results does not yet exist. Three areas are of concern here: (1) the extent to which the CBC results are representative of bird populations in Britain; (2) the extent of normal ecological variation in population numbers; and (3) the need for techniques to control for the many potential biases that can arise in the analysis of extensive data sets gathered without defined sampling protocols. Each of these points needs more detailed consideration here.

Ideally, the CBC data set should be based on a representative sample of the farmland and woodland habitats in Britain. In practice, each plot is individually chosen by the observer, and the censusing of each continues only as long as the observer's willingness to do the work involved lasts. Such self-selection of sites has a corresponding potential for bias in sampling. What checks have been conducted to date are, however, relatively reassuring. One risk of great importance for monitoring is that observers might select sites with farming regimes especially favorable for birds. As noted elsewhere in this volume, however, the composition of the farmland CBC plots in fact reflects farming practices and land class distribution over a large part of England and has been consistent in this over the period 1962–81, despite major shifts in agricultural management (Fuller et al. 1985). Land classes poorly sampled are essentially those remote from centers of population (e.g., in the Highlands of Scotland and in Wales). Armed with this knowledge, it is possible to define the regions in which the CBC is valid as a total population monitor, at least for farmland. The absence of the equivalent study for the woodland CBC plots continues to be a significant weakness of the scheme. This uncertainty is in marked contrast to the controlled statistical design of the North American Breeding Birds Survey, in which the location of survey routes has been carefully determined from the outset. This to my mind reflects a major difference in emphasis in monitoring between Britain and North America, the former viewing the results as of interest, the latter as a viable management tool.

Another possible concern about using the CBC results for monitoring is that observers might abandon sites where bird numbers have decreased, that is, once they are no longer as good for birding. O'Connor and Fuller (1984) reported an analysis of the stated reasons for giving up CBC plots and found no evidence of such an effect.

A second generic difficulty is that we know little of the normal fluctuations of bird populations. Suppose, for example, that the CBC scheme were to report a 25% decrease in the number of the migratory sedge warbler (*Acrocephalus schoenobanus*). What answer can be offered to the question "So what?" After all, British species can decrease by factors of 8–10 during a severe winter, yet recover quickly, and migrant populations are particularly labile. Hence a single year's decrease, though statistically significant, need not be biologically significant. A sustained decrease, though, is likely to reflect environmental change, as with the whitethroat (Winstanley et al. 1974), peregrine falcon (Ratcliffe 1980), sparrowhawk (Newton 1986), and various farmland species (O'Connor and Shrubb 1986a, 1986b). In all of these studies, both the passage of time and a variety of corroborative evidence were necessary to establish the ecological significance of population changes detected. For the CBC scheme, therefore, the perceived need is for improved understanding of the dynamics of British bird populations, both over time and over space, to improve the assessment of the biological significance of population changes observed. A declared policy aim for the CBC scheme is to conduct periodic (about every 5 years) reviews of population trends of species or groups of species in relation to variation in climate. The detection of parallel population trends in groups of species sharing common ecological requirements offers one powerful way of linking bird numbers to identified environmental changes and is expected to be a major feature of the new program of analysis. Recent examples of this approach can be found in O'Connor and Shrubb (1986a, 1986b). This emphasis on general interest and ecological analysis of the results is less evident in North American use of ornithological data banks, with only a handful of authors at all active in this field (e.g., Bock and Root 1981; Bock and Ricklefs 1983; Bock 1984; Brown and Maurer 1987).

Finally, controls of some type are necessary if an observed change in numbers is to be attributed to a specified environmental factor, both because of the ecological variation just considered and because of the potential for biases other than those already considered. Readily applicable techniques for this have been possible only recently, following computerization of the available data (O'Connor and Shrubb 1986a). It is probably fair to claim that the CBC data set has become so extensive that appropriate controls for most possible biases can now be found within its domain.

Concern over issues of bias led the BTO in 1984 to switch publication of the annual CBC reports from the Trust's scientific journal, *Bird Study*, to its newsletter, *BTO News*. Historically, the CBC results have been published in *Bird Study*. Given the normal standards of scientific caution required of such a publication, a difficulty arises over the variety of consistency checks that ought to be made to ensure proper interpretation of the results. Inevitably, such checks are repeated each year and therefore come under editorial pressure about the space they consume. In addition, a rather low proportion of the volunteer participants in the scheme are interested in the methodological checks. Over time the result has been to minimize the effect of the cautions and caveats that need to be presented, and the CBC results have often been reported as though they were national trends equally applicable to all parts of Britain. Under the new system, publication in the newsletter distributed to all BTO members ensures the desired feedback. On the other hand, while it does not preclude the results being misused (e.g., as though they were national indices), the authority for such misinterpretation is overtly the citation of a newsletter article rather than a formal scientific journal. Thoughtful users of the CBC results, however, will draw on formal scientific papers in which all caveats are properly evaluated. This problem seems to be more pronounced in Britain, where the tradition of annual reporting of recurrent results in scientific journals is well-established. In North America, routine reporting of data is less prevalent: it is more often relegated to the bulletins of the data gathering scheme itself, if published at all (Engstrom 1989).

Despite the reservations mentioned previously, a case can be made for simple indexing of certain populations. For migrant species, in particular, few sources of information are available to track environmental influences on their numbers in the wintering grounds, and an annual index, however poor, may be valuable for that reason alone. For resident species, though, other means can probably identify adverse environmental changes in Britain more efficiently than can a CBC index for individual species.

Improving the Efficiency of the CBC Scheme

How Many Plots Are Needed?

Species Coverage

To a person familiar with the bird community of farmland or woodland in Britain, the list of species currently covered by CBC indices contains some notable absentees, such as house sparrows (*Passer domesticus*), rooks (*Corvus frugilegus*), and reed warblers (*Acrocephalus scirpaceus*). This is because the CBC technique is based on the identification of defended territories and fails to work satisfactorily with colonial or semicolonial species. Many less common species are absent from the list because they occur on too few plots to meet the 30-plot requirement for the annual reporting of an index value. This requirement has not been rigorously observed for all species in recent years, because to do so would break the continuity of published indices for the species concerned. This problem has been brought about by the falling samples of CBC plots in general and is therefore an urgent issue to be addressed if the CBC is to be stringently limited by available funding and associated contractual requirements. The breach of minimum sample size is possibly acceptable in the short term, but in the longer term the practice risks opening the sample to the random walk effect described by Geissler and Noon (1981). Many of the analyses undertaken in the last decade become quite suspect if the underlying continuity depends on a very few plots in particular link years.

Plot Distribution

An important issue for the cost-effectiveness of the CBC scheme, therefore, is the size of sample needed to detect a given change with statistical reliability. Trends detected to date have been those for which the available samples were actually adequate to reveal the trend concerned despite the variability of data. What is less well understood is the extent to which the current pattern of data collection may limit the detection of other trends. Sampling efficiency is in general improved if effort is distributed in proportion to the standard deviation of densities within region (Snedecor and Cochran 1967), but CBC plots are in practice more numerous in southern England, where for many species densities are greatest (O'Connor and Shrubb 1986a) and, by implication, most uniform. Little thought has been given to optimizing CBC plot distribution for statistical efficiency, despite the constraint imposed on total plot numbers by the need to have the map interpretation for the CBC scheme undertaken by a professional staff. Ways of reducing the major staff commitment involved have been considered. One possibility would be to interpret only some of the maps for the most common species while doing all of the returns for the scarcest species. A major difficulty here is that few observers would accept that part of their returns should go unused. Most observers already wish to include all species they find on their plot, even though some of the species do not lend themselves to CBC analysis. A deliberate policy of selective analysis would therefore be unacceptable. This issue exemplifies one of the problems peculiar to an organization such as the BTO, a conflict between what is objectively optimal on cost grounds and what is acceptable to the volunteers whose time and effort are as essential as funding. It is unlikely that North America differs much from Britain in this respect.

Index Computation

Another statistical issue of concern to the CBC scheme is the precision of the CBC index. The current procedure is to estimate a percentage change from year to year and apply the confidence intervals for this change to an index value prorated on the earlier year. The procedure is undesirable for two reasons. First, as pointed out by Geissler and Noon (1981), errors can accumulate over time as successive index values are chained together, even though each value is itself within its year-on-year confidence band. This process is most severe with small samples, but is less likely with the larger samples of the CBC scheme. Thus, Moss (1985) found an at most 25% deviation over a 20-year period, on subjecting simulated data typical of the CBC to the chaining process. He also found that the calculated index values for individual species were usually highly correlated with directly computed densities for the same year. However, for one species, the spotted flycatcher (*Muscicapa striata*), he found a low correlation, apparently because new plots entering the CBC scheme in certain years held more spotted flycatchers than those leaving the scheme. It is not known to what extent this problem influences the CBC results, and it is not currently controlled for. One must also note that the Geissler and Noon (1981) random walk problem will influence the calculation of regional or other subset indices to a greater extent than it will the indices based on all plots in the country.

The second weakness of the present CBC index computation is that it uses only part of the available information. Each index I_n is calculated only from data for plots censused both in year n and in year $n - 1$, yet a significant number of plots censused in year n may also have been censused 2 years earlier (year $n - 2$). Even with a 20% replacement each year, some 64% of the plots censused in year n will also have been surveyed in year $n - 2$ (and 51% of them also in year $n - 3$, and so on). Hence, the index for year n can be calculated either by chaining the percentage changes between years $n - 2$ and $n - 1$ and between years $n - 1$ and n or by estimating the percentage change between year $n - 2$ and year n from the 64% subsample in common, in either case then prorating on I_{n-2}. In general, these two routes to estimating I_n will not yield identical values. Mountford (1982, 1985) has developed a method of combining such multiple pathways to I_n. His method yields significant reduction in the confidence interval about each index value as compared to the standard CBC method, thus providing greater statistical efficiency in the use of the data. This greater efficiency, however, is won at the expense of requiring assumptions to hold over longer periods of time, and this has to be checked expressly, using a test provided by Mountford. Preliminary studies suggest that Mountford's procedure may be applicable for periods of a decade or so at a time. If so, it could readily be used in the anticipated periodic reviews of long-term trends in the CBC data set without necessitating annual recalculation of previously published index values. This procedure has potential relevance to, for example, the Breeding Bird Survey (BBS), because it is markedly less computationally intensive than the Geissler and Noon (1981) method, without losing much of the statistical sophistication of that procedure.

Despite these two problems, it must be noted that the Bailey (1967) index obtained by the chaining of year-on-year population changes has been proven a very valuable tool in the evolution of long-term studies of bird populations in Britain. Its very simplicity, coupled with the robustness provided by reasonably large sample sizes, has allowed many researchers lacking major statistical expertise to make effective use of CBC data, particularly in the trial-and-error approach needed in research. In contrast, the BBS data have proved less amenable to analysis: the sophistication of the Geissler and Noon (1981) algorithm seems to have defeated many of the less statistically adept researchers attempting their own analysis, and has necessitated greater reliance on the BBS personnel to provide the requested trend data. Despite the generous provision of such support (at a higher rate than the BTO has ever been able to supply to its data users), such reliance inevitably limits the flexibility of research efforts. I suggest that this has been at least in part responsible for the great emphasis in North America on the use of BBS data for monitoring, while in Britain emphasis has fallen more on research than on monitoring use of the Common Birds Census data.

Additional Censusing

Milner and Hornby (1977) noted that the absence of a national index of bird populations in Britain could be met by increasing habitat coverage using the CBC scheme or by the introduction of a system of point counts in areas in which the CBC was inappropriate, for example, because of low availability of participants willing to make the time commitment to a CBC plot. Trials of these techniques in British habitats showed that they could provide the information required (Fuller 1983; Fuller and Langslow 1984), though the need for observer training could prove a limiting factor (Verner 1985). In practice, however, the CBC scheme is funded under a contract for the provision of ornithological services to the statutory Nature Conservancy Council, and financial limits to the contract funding limit the possibility of doing this. The Trust has therefore accepted that the main strength of the CBC scheme lies in lowland farmland and woodland (excluding coniferous woodland), and that the scheme provides a means of gathering annual census data in these habitats. Here, lowland farmland includes all intensively used agricultural land. Coniferous woodland is excluded partly because the majority of it lies in areas where BTO members are sparsely distributed and partly because of its low conservation value. Semi-natural broadleaved woodland, on the other hand, is an extremely valuable habitat in Britain, both because of its absolute scarcity and because of an increasing trend to replace it with softwoods, so information from the habitat would be particularly valuable. The current expectation, therefore, is that the program should concentrate on these habitats.

Regional Indices

An alternative to comprehensive monitoring of all habitats to achieve a national index of bird numbers is to analyze the data on a regional or habitat basis. In this way regional indices might be produced for areas in which the CBC scheme is strong, while data would manifestly not be available for other areas. This option has been considered by the Trust, but has been ruled out on two grounds: (1) the cost of staff time to prepare the necessary annual indices, and (2) the absence of any systematic program for use of the resulting indices as an early warning system. Both problems are potentially soluble by resorting to computer use, but in practice the return for undertaking this work annually is unlikely to be worthwhile. On the other hand, the long-term potential for comparing regional trends is particularly valuable, especially if the regions are chosen to reflect major classes of land use or are areas undergoing significant changes in agricultural practice. However, current policy for the CBC scheme calls for greater effort to improve regional representation within the farmland and woodland samples, within the limit of about 100 plots for each sample set by the funding for CBC staff. Success in doing so would lend more of a national character to the CBC index, but at the same time would make the index incompatible with that of the earlier years in which the samples were not distributed representatively (Fuller et al. 1985). This perhaps highlights the need for more systematic investigation of the homogeneity of the CBC samples (especially of the woodland sample), perhaps using techniques offered by Mountford (1985) and Fuller et al. (1985). These same issues arise in North America, where the huge cost of routine processing of the Breeding Birds Survey data has limited reflective publication on the Survey's results to occasional publication (Robbins et al. 1986).

Alternative Monitoring Methods

The Constant Effort Sites Scheme

In recent years in the United Kingdom, considerable interest has developed in the application of bird ringing efforts to population monitoring. Investigations of the possibilities of using annual ringing totals have generally been unsatisfactory, with too many uncontrolled intervening variables prohibiting any form of standardization of the data. O'Connor and Mead (1982, 1984), however, showed that an index of stock dove numbers based on a standardized ringing total was highly correlated with the results of the CBC's scheme. However, this index was specifically selected for the species only after substantial investigation and cross-checking of potential biases and does not seem to be valid as a general index. Mason and Hussey (1984) also attempted to devise population indices based on ringing totals (of nestlings) and obtained several parallels with known population changes. However, the majority of the trends they demonstrated lacked validation, making it difficult to know what significance to attach to them. Interest in using United Kingdom ringing data for monitoring has therefore shifted to a concept known as the Constant Effort Sites (CES) scheme. This scheme is based on a protocol already successfully in use in Germany (Berthold et al. 1986). The idea is that participants in the scheme undertake to standardize the amount of their netting activity on a site by controlling the amount of netting used and by undertaking trapping on a regular schedule through the breeding season. Under these conditions the absolute totals of birds trapped should be consistent from year to year, barring successional changes or habitat modification. By examining the catches of adults obtained in the early part of the season, an assessment of population change is possible. Data obtained later in the season can be used to compute ratios of juveniles to adults as a measure of annual productivity, and information as to retraps between years can be used to estimate survival rates.

Since 1981, the CES scheme has run on a trial basis, funded by what is effectively a surcharge on banding permit fees, and is currently the subject of intensive methodological investigations. Little has been published by way of formal study of the scheme, though several internal BTO documents have reported on the scheme's progress, and annual reporting in the public domain has started (Baillie and Holden 1988). Observers are asked to visit their site once in each of 12 10-day periods from May through August. The same set of standard net-sites, each using the same size and type of net, must be used on each visit. Two protocols are under investigation at present. One is rigid and prohibits any additional netting within 400 m of the site and allows only the 12 trapping visits. The other is flexible, permitting use of additional net-sites and additional trapping visits, but holding these data separate from the standardized work. Emphasis is placed on using sites homogeneous in habitat, particularly for reedbed and thorn scrub habitats well favored by warblers but poorly covered by the CBC scheme. (Warblers in Britain are considered a group of potential conservation concern.) A particular aim of the CES scheme is to determine how the population dynamics of particular species vary between habitats. Batten (1973) provides the major case study, for the European blackbird (*Turdus merula*), of this type undertaken to date in Britain.

Some interesting philosophical problems are associated with the use of the CES scheme for monitoring. First, if the results for all species surveyed by the CES method were to prove well correlated with the CBC, the CES method would add nothing to the information on trends established by the monitoring program. The correlation, however, adds confidence to the validity of either scheme as a monitoring tool. Second, a priori one might expect species differences in temporal trends obtained in the two schemes. For example, reed warblers feature prominently in mist net catches but are poorly censused by the CBC scheme because of features of their territorial behavior. Hence, failure to find a correlation for individual species does not invalidate the potential of the CES method, but leaves the meaning of the CES index for that species in question. Third, if divergences between CES and CBC results are obtained, how does one interpret CES data for species that are not monitored at all by the CBC? Similar questions arise in relation to the concept of productivity monitoring, where the BTO's nest record scheme provides the calibrating dataset. A major worry about the CES scheme is that it has now reached its seventh year without the detailed statistical analysis that Taylor (1965) provided for the CBC scheme after just 3 years. Such schemes tend to develop a momentum of their own and to be difficult to discontinue should their results prove inviable. Despite these caveats, possibly overemphasized here against the background of the very thoroughly researched CBC scheme, research conducted to date has been promising. First, the annual capture patterns for a given species tend to be relatively consistent from year to year, and seasonal recaptures indicated that a large proportion of the adult population is caught annually. Second, where CBC and CES data have been compared within similar habitats (the habitat coverage for the CES scheme differs markedly from that of CBC), there is good agreement in the overall trends apparent. These early results suggest that the CES scheme may prove a useful complement to the CBC monitoring program.

Coverage of Scarce Species

The CBC's name—the Common Birds Census—emphasizes the basic significant bias of the scheme towards birds that are particularly abundant. These birds are often habitat generalists and are not the ones that are most likely to be affected by selective changes in land use. An important issue, therefore, is how to index the populations of scarcer species. For some years the Trust reported annually a Scarce Species Index calculated by combining the results from all plots that supported the target species, irrespective of the habitats involved. Two difficulties, one technical, the other practical, have arisen over this index. First, when an index is formed by combining data from a variety of habitats that have characteristically different densities of a species, any change in the annual composition of the CBC returns has a direct effect on the index, quite independent of the changes in bird numbers. Second, the use of a scarce species index promotes the inclusion of so-called special plots for which special pleading is possible, for example, that a plot contains breeding nightjars (*Caprimulgus europaeus*) or the like. The temptation has been to include such a plot to obtain the data for, in this case, the nightjars, but in so doing the Trust staff undertakes a commitment to analyze all the returns from that plot, for common species and nightjars alike. The inclusion of special plots has proven to be far from cost-effective, and the index was discontinued following the review reported by O'Connor and Fuller (1984). Nevertheless, even the most recent annual report of the CBC scheme continues to base results on mixed habitat samples for 13 species (Marchant and Whittington 1988).

If rare species are excluded from the monitoring scheme on these grounds, what options are available? One possibility is to recognize that there are several types of rarity: some species are widely distributed in small numbers, others have a very local distribution, and yet others are widespread in reasonable densities but only where locally available habitat is present for them. Against this background, the optimal procedure is to use a large-scale low-intensity survey to establish where these species are present, followed where necessary by more detailed survey work targeted on the sites known to hold the species of interest. This type of monitoring has long been undertaken by the BTO in the form of single species surveys. These surveys are planned by a small working group of experts on the species, appropriate techniques are developed from personal knowledge or through pilot field work, and the BTO membership at large is then invited to participate in the survey of species (or habitat) concerned in a particular year. Coordination of this observer network is achieved through a system of regional representatives, each of whom is responsible for the local organization of coverage for their area. Surprisingly, this approach has hardly been tried in the United States, presumably because most of the species charismatic enough to attract funding with which to administer such a survey are already so limited in distribution and status that they are already monitored by professional workers.

A possible new use of the CBC scheme data would be as an initial screen for single species survey candidates. For many less-common or scarce species the proportion of survey plots on which the species is recorded is well correlated with its local abundance. This is true both interspecifically (Fuller 1982; O'Connor and Shrubb 1986a) and intraspecifically (Gibbons 1987). Hence, even though a species may be too scarce on the CBC plots to generate enough clusters to allow computing a CBC index, changes in the frequency of its listing on the CBC plots may be informative. Marchant (1980) provides an example of the effective use of this technique in tracing the recovery of the European sparrowhawk from the effects of organochlorine pesticides. It should therefore be possible to use the CBC data for very scarce species to identify those in need of greater monitoring attention through the mechanism of the single species survey. Cornell University's Laboratory of Ornithology has used a rather similar approach in developing an information base in respect to species of management concern (G.S. Butcher, personal communication).

Even with such maximized exploitation of CBC data, many species – particularly those in habitats not surveyed by the CBC in Britain – remain to be monitored. The use of large-scale atlases of breeding birds is now considered to be a useful approach here. The first such atlas of Britain and Ireland is that of Sharrock (1976), for which the BTO and the Irish Wildbird Conservancy (IWC) surveyed some 4,000 atlas squares, each a 10- × 10-km unit of the Ordnance Survey National Grids, and mapped proof (or absence of proof) of breeding of all species on the two islands. A subsequent *Atlas of Wintering Birds in Britain and Ireland* (Lack 1986) mapped the midwinter distribution of each species, the index of abundance being related to the number of birds found in timed searches of each 10-km square. The concept of a quantified distribution atlas has been extended in the light of the success of the winter project, and BTO and IWC fieldwork to map relative numbers of all breeding species started in 1988. In this work, relative abundance is to be assessed from a frequency measure, the proportion of tetrads (the 25 2-×2-km squares within each 10-km^2 atlas square) in which each species is recorded. This atlasing technique can then be repeated at 20- or 25-year intervals to provide a periodic overview of relative abundance and distribution of each bird species breeding in Britain and Ireland, yielding a crude but probably effective monitoring tool for the general run of species in the two countries.

Products from the Monitoring Program

A significant shift in thinking about the purposes of a monitoring program has revolutionized the BTO's work with CBC, WBS, and other such data in recent years. Given the high cost of servicing the gathering of field data by amateurs for the CBC and other programs, the indices of population levels generated are no longer seen as sufficient product for the public money spent with the Trust by the Nature Conservancy Council (NCC). Instead, the emphasis has shifted to producing other products, especially research papers, relevant to the applied needs of the NCC. The possibilities for such products are therefore considered in the following sections.

Population Studies

Despite the deficiencies in the present CBC indices, it has proven possible to use them in studying the population dynamics of various species, especially the most common ones, in Britain. Snow (1966) pioneered the use of the BTO's data for this purpose, in a detailed study of the biology of the European blackbird. Batten (1977) subsequently deployed data from the full range of the BTO's annual surveys to study this species' population dynamics in greater detail. Both studies were remarkable for being undertaken at a time when the data concerned were available only as clerical records. As part of an initial investigation of the potential of computerized records, O'Connor (1980a) subsequently studied the population dynamics of the great tit (*Parus major*) in Britain and showed that the results obtained from such extensive data banks were very similar to those drawn from the intensive studies of this species in Wytham Wood in Oxfordshire (Perrins 1965). As a result, one can expect greater use of the BTO data banks for population studies of various sorts. One problem here is that the existing data are not yet fully computerized, requiring significant work before they can be used for studies of the national populations of target species (see below). The immediate priority, therefore, is to study the impact of severe weather on bird populations in Britain, since this requires less comprehensive data files. Early examples of the use of BTO data for this purpose include studies by Williamson (1975b, 1976), O'Connor and Cawthorne (1982), O'Connor et al. (1982), and Baillie (1984).

An important strength of the BTO in using monitoring data for studies of these types is that most of the relevant schemes are organized from the BTO's offices. As a result, all relevant files are available at a single location and under homogenous conditions regarding access. This is probably the single most important factor behind the BTO's record in using the extensive field data of amateurs for scientific purposes. Thus, for most common species, data on population levels are available from the Common Birds Census, data on timing and success in breeding can be obtained from the Nest Records Scheme, data on movement and survival can be obtained from the Ringing Scheme, and data on winter feeding can be obtained from the Garden Birds Feeding Survey. Examples of how these data can be integrated within a species can be found in the work by Snow (1966), Batten (1977), O'Connor (1980a, 1982), and O'Connor and Mead (1984). Although the dispersal across several agencies of data from such North American schemes as the Breeding Bird Survey, the Christmas Bird Count, the Cornell Nest Record Program, and the Bird-Banding Program must hinder ready development of single species studies based on data integration such as described earlier, it remains surprising that major population studies based on these data have not appeared. Presumably funding problems, aggravated by a view in some quarters that data gathered by volunteers cannot possibly be taken seriously, underlie this gap.

Habitat Studies

Although the CBC is theoretically an indicator of environmental change, it is in fact not suitable for monitoring habitat loss as such. It is simpler, for example, to study gross habitat losses from aerial photographs or satellite imagery, procedures that are not confounded with distributional biases on the part of the observers. On the other hand, the CBC data are particularly useful in relation to the modification of bird habitats, provided the habitat data submitted by observers is of high quality.

Data on habitat modification are required for several different purposes. One is to assess the likely effect on bird populations if currently observed rates of habitat modification continue. Such information can also be useful in evaluating projected land use patterns. A second use for habitat modification studies lies in determining how to manage habitats for a particular species, either to ameliorate the effects of, say, economics-driven land-use changes or to maximize the carrying capacity of nature reserves for the species of interest. Several approaches to the analysis of habitat modification effects are possible. One is to conduct cross-sectional studies of a number of different plots that vary in the habitat characteristics of interest. Here the number of territories on the plot constitute the response variable and can be related through a variety of statistical techniques to the habitat variables. This approach showed a fairly large number of habitat correlates of farmland species where cluster data have been used (Morgan and O'Connor 1980; O'Connor and Fuller 1985; O'Connor 1987). Similarly, woodland habitat preferences, at least at a gross level, have been established from CBC data (Williamson 1968; Williamson 1974; Batten 1976; Fuller and Taylor 1984). In these studies the essential requirement is that the differences in habitat across plots are larger than any variations in census efficiency for the target species in these habitat types. Perhaps the classic example of this type is Williamson's (1969a) study of how wrens (*Troglodytes troglodytes*) expanded their habitat use on British farmland as the population recovered from a population crash due to an extremely severe winter.

A second form of habitat study exploits the before and after nature of the data gathered continuously by CBC participants on plots on which a particular habitat change occurs. On agricultural land, for example, examples of such habitat changes might be the removal of a pond, the grubbing-out of a hedgerow, the removal of a small woodlot, and the canalization of a watercourse. Such events often occur unpredictably, but the availability of before and after data provides an extremely valuable case history. Thus, Bull et al. (1976) traced a sequence of population changes on a long-running CBC plot on a Norfolk farm to specific events in its management history. Single instances of such studies are almost anecdotal, but the simplicity of the story they tell can be extremely valuable in conservation education, and the accumulation of similar case histories generates statistical weight.

A significant issue relating to the use of monitoring data from the CBC scheme for habitat studies relates to the scale of data to be used. The raw observations gathered are the bird registrations, while the clusters constitute derived information. The use of the original registrations potentially offers the finest discrimination, in that it guarantees that a particular bird was using a particular habitat element at that particular time. In contrast, clusters represent an integration of the spatial information and may link registrations that properly do not belong together, so their boundaries may encompass a habitat in fact unused by the birds concerned. On the other hand, use of individual registrations can be problematical, because some may involve the same bird seen on more than one occasion, thus influencing the degrees of freedom. Individual registrations are also biased toward territorial behavior, which constitutes but a subset of the bird's total behavior. A system of spatial integration could, therefore, detect features that would have otherwise gone unseen. For example, most song thrushes (*Turdus philomelos*) might be seen singing in tall trees, but their association with the number of ponds on a farm would not be detected in such observations, even though they feed for invertebrates in the soft ground around the ponds. One problem with the use of specific case studies is that such work can readily be generated by individual field workers, while the BTO CBC scheme is intended to be a national monitoring program. It can therefore be argued that the BTO's research program should concentrate on the use of the national data set (Milner and Hornby 1977). Such studies are, however, data extensive and require good computing facilities and the existence of the historic data in appropriate files. Such facilities have been available to the BTO only during the 1980's, but since then have greatly influenced the Trust's research program. Examples include work by Morgan and O'Connor (1980), Pearson (1980), and Fuller and Taylor (1983), all of which used subsets of the CBC returns to obtain broader-scale pictures of population dynamics. Such analyses do need careful undertaking, however. Johnson (1981) points out that the statistical issues are not trivial, since (1) birds may respond in a nonlinear fashion to habitat features, (2) the confidence zone of statistical predictions needs defining, and (3) even then the particular studies need to be validated with respect to their overall representation in the country as a whole. One special strength of the CBC scheme is its ability to provide both the wide-ranging data bank needed for this type of analysis of habitat correlates and the range of before and after case histories with which to cross-check these statistical conclusions.

The ready availability of good quality habitat data, at least for agricultural census plots, has been invaluable in permitting the British studies reviewed here. This suggests that one of the major weaknesses in the North American databanks is the absence of good habitat data directly associated with the census points. The Breeding Bird Census—the scheme most analogous to the United Kingdom Common Birds Census—plots are too sparse to meet the need. The U.S. Fish and Wildlife Service has conducted a 1-year survey of habitat at BBS routes, and the results will be interesting to review in this context. To study the effects of habitat modification on bird populations, however, such data must be collected periodically, if not annually. Data are already available in the United States to show that agricultural bird populations are being affected by changing land use practices (e.g., Natural Research Council 1982), and the issue of habitat fragmentation and its effect on migrant birds has already generated a substantial literature (e.g., Robbins 1980; McLellan obbinset al. 1986). The routine collection and analysis of habitat data thus seems, in the light of British experience, an extraordinary omission.

Dynamics of Habitat Use

An important interplay of monitoring information and habitat use relates to the dynamical use of habitat by birds. Theoretical work by Brown (1969) and Fretwell and Lucas (1969) showed that at high densities species may expand the range of habitats they occupy. In some circumstances, densities in these secondarily occupied habitats may even exceed the densities observed in the preferred habitats (van Horne 1983). Hence, if one took the widely held view that relative densities reflect the relative values of different habitats, one would conclude erroneously that the habitats occupied at high densities were the most desirable for conservation management. A significant part of the BTO's recent research with CBC data has therefore focussed on habitat dynamics. Major reviews of the underlying theory are provided by O'Connor (1980a, 1985) and O'Connor and Fuller (1985), and examples of how individual species are affected are given by Williamson (1969a), Williamson and Batten (1977), and O'Connor (1980b, 1982, 1986). One interesting product of such research is Pearson's (1980) suggestion that the temporal stability of foliage layer use may be a better predictor of such use than is the classic foliage height diversity index of MacArthur iversityand MacArthur iversity(1961). He found that southern English woodlands with the preferred foliage layers present were less variable in their CBC counts than were woodlands lacking these layers. Hence, at least for species with labile populations, annual surveys of species presence or absence in particular habitats could yield information on habitat preferences without resorting to detailed census work. The development of such new insights into avian habitat needs is a significant basis for the BTO's interest in such use of the monitoring data.

Studies on Habitat Succession and Avian Responses

Reserve management in Britain is frequently concerned with the modification of successional change. For this, long-term census data are especially valuable, and researches of this type, based on the longer running woodland CBC plots, are likely to receive greater attention in the future (e.g., Taylor 1983b; Fuller 1986). A particular difficulty here is that the BTO's CBC volunteers are competent birdwatchers rather than trained ecologists. The detailed habitat recording required for successional studies, therefore, have to be acquired by professionals. Several early woodland CBC studies, mostly based on the expeditionary approach already mentioned, were in fact directed to successional studies (Williamson 1972a, 1972b, 1975). In these studies, the detailed vegetation data needed were either gathered by professional workers accompanying the volunteer teams or were taken from forestry records. More recently, Fuller and his colleagues (Fuller and Taylor 1983) have led new research thrusts in this area.

It is worth noting that their work avoids the excessively detailed vegetation data-gathering seen in many North American studies of bird habitat, but continues the tradition of Williamson's early studies by focusing on habitat descriptors that are immediately relevant to forest and woodland managers.

Site Assessment

Although the CBC method is not intended to provide a national program of site assessment, it can have value in providing information about individual sites. Of major interest here are sites of special conservation value, such as nature reserves and the United Kingdom's Sites of Special Scientific Interest. Such sites, however, provide a special dilemma for the CBC scheme, because their protected status means that their bird populations are artificially protected against the environmental changes that the scheme was designed to study in the first instance. One resolution of this dilemma may be to recognize that experienced CBC volunteers are a resource more valuable than the CBC scheme, and devise ways of using their pool of experience for conservation evaluation. Williamson and his colleagues (Williamson 1969b, 1974; Batten 1976) organized an early and very successful CBC training program of expeditionary fieldwork in habitats or areas of special conservation interest. The program provided not only training opportunities but also a wealth of hitherto unavailable data on the typical breeding densities of species in these habitats. The program gradually dwindled as the CBC scheme developed, in part because the same core of enthusiasts repeatedly participated, undermining the training component then being emphasized, and in part because of concern that the restricted time span of such mapping censuses might bias results. This last issue has since been examined experimentally and found not to be a problem (Edwards 1977; O'Connor 1980c), and the BTO has recently resumed a program of combined CBC training and site investigation (e.g., Fuller and Taylor 1983).

Conclusion

Thinking about the nature and purposes of a bird monitoring program in Britain has changed dramatically in the course of the 25 years for which the CBC has now run. Emphasis has shifted from the production of simple indices of population levels to a sophisticated program of research in avian ecology addressed to pressing issues of avian conservation. Some of the answers generated are broad, providing background information on such questions as regional and habitat variation in typical densities. Others are quite specifically addressed to issues in theoretical ecology, to generate understanding of how bird populations function. Finally, yet other questions are strictly applied, either to the assessment of the bird populations of key sites or to the continued improvement of the cost-effectiveness of the overall program. It has become absolutely clear that to freeze the CBC scheme into a fixed regime of fieldwork, analysis, and routine reporting would mean its rapid demise. Instead, the challenge for the BTO's leadership is to recognize the unfolding potential for the Trust's monitoring programs and to exploit that potential as fully as possible without destroying the elements of standardization that must be retained. Such a program is not easily imported into North America, with its different cultural traditions and much greater per capita land mass than Britain. Nevertheless, some elements would be particularly valuable in enhancing the rich data banks of bird population information in North America. Greater emphasis on acquiring habitat data in parallel with the bird data, increased research effort outside the monitoring context (and particularly in introducing bird data bank studies to the ecological literature in North America), and a systematic program to promote the standing of data bank-based studies would likely prove especially rewarding. Taylor (1989) provides a recent review of the BTO's bird monitoring program in the context of long-term ecological research that develops the generality of the specific points made here.

Acknowledgments

This paper is based on work undertaken while Director of the British Trust for Ornithology and funded under a contract from the United Kingdom Nature Conservancy Council. My participation in the Patuxent workshop was funded by the U.S. Fish and Wildlife Service. I am grateful to both for their financial support.

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Part III: Scissor-tailed Flycatcher Analysis

We selected the scissor-tailed flycatcher (*Tyrannus forficatus*) data as a sample data set for analysis because the flycatcher's breeding range is almost completely encompassed by the North American Breeding Bird Survey. Populations vary greatly in abundance, both among States and among routes within States. Also, the species apparently experienced a population crash in the mid-1970's, but has been recovering during the 1980's. These features make it difficult to adequately summarize population trends.

Although several participants in the workshop presented analyses of the scissor-tailed flycatcher data set, only three authors submitted papers for the proceedings. Two of the papers present route-regression analyses (although differences exist in the application of the method), while the third paper presents a nonparametric analysis. The route-regression analyses differed in their approach to accommodating the decline in the mid-1970's. Collins (1990) modeled the decline and subsequent population increase by estimating trends within subperiods of the 1967–87 interval, while Sauer (1990) presented annual indices of abundance that displayed the decline. Although it is unlikely that a long-term trend can be estimated from these data, both analyses were successful in modeling the dynamics of the population over the interval. Moses and Rabinowitz (1990) use the scissor-tailed flycatcher data to illustrate their model fitting procedure (The scissor-tailed flycatcher data set is available to individuals who want to use it for comparative purposes; it can be obtained from the editors.)

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Analysis of Scissor-tailed Flycatcher Population Changes

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The data were analyzed (1) separately for each State, (2) separately for each physiographic stratum, and (3) for all States together. In order to assess whether a single trend could be used to analyze the entire 22-year data set, the analysis was done for five periods of time: (1) the most recent 5 years (1983–87), (2) the period up to the most recent 5 years (1966–83), (3) the most recent 10 years (1978–87), (4) the period up to the most recent 10 years (1966–78), and (5) the entire data set (1966–87). In the analysis presented here, no adjustments were made for observers, and the area weights assigned to the routes were the same for all time periods. Since the routes which are run change with time, the area weights should be reassigned for each time period under study. For example, in Kansas there were 37 usable routes in the period 1966–83, but there were only 22 usable routes in the period 1983–87. This is caused partly because some routes were not run in the most recent 5-year period. In light of this, the area weight assigned to these routes should be larger for the most recent 5-year period, but this was not done because I did not have the required information.

The results of the trend analysis for the 22 years of data are shown in Table 1. This table shows several different methods of presenting the estimates of trend and should allow comparison with other analyses.

The estimated trends were negative for all States with more than 10 routes. The declines were significant ($P < 0.05$) for Texas, Oklahoma, Arkansas, and Kansas. These are the States with the largest number of routes, and the lack of significance for Missouri and Louisiana may reflect the small number of suitable routes run in those States rather than a stable population. The mean count per route was so small that the estimate of trend may have a substantial bias for all States except Texas and Oklahoma.

The analysis by physiographic stratum revealed a wider range of estimated trends. This may be partly due to the large number of strata which hence tend to have fewer observations than the States. There was a significant ($P < 0.05$) increase in stratum 53 and a significant decline was detected in four strata: 8, 34, 35, and 56. All 16 routes in stratum 53 are in Texas, and the estimated increase is counter to the overall estimate of decline for that State. The increase in stratum 53 is counteracted by the significant declines in strata 8, 34, and 56, which combine to give an overall estimate of decline for the State.

The analysis separating the trend into smaller time frames is shown in Table 2. In this table the trends are presented as percentage change that would occur over a 10-year period, and the number of routes used to calculate the trend is shown in brackets. It can be seen that this method of presenting results can reveal unrealistic measures of trend when the number of routes and the time frame are small, such as that for stratum 5 in the period 1983–87. In addition, since the analyses for different time frames are sometimes based on different routes, there is a lack of consistency between the analyses for different time periods. For example, in stratum 19 the estimated trend is negative for the periods 1966–78 and 1978–87, but the combined trend for 1966–87 is positive.

The important thing to note in Table 2 is the lack of consistency in the estimates from different time periods. For the combined strata the estimated trend is negative for the initial portion of the survey, followed by a positive trend in the more recent years. The decline was significant for the period 1966–78, and the increase was significant for the period 1978–87. The results for the individual States for these time periods reveals a similar pattern of decline followed by an increase for six States: New Mexico, Texas, Oklahoma, Arkansas, Kansas, and Louisiana. The declines were significant for all of these States except New Mexico, which had only a few observations, and the increases were significant only for Texas. Similarly, the trends for the strata reveal a decline in the period 1966–78, followed by an increase for the period 1978–87 for 10 strata: 55, 53, 32, 7, 54, 33, 4, 6, 35, and 56. These declines were significant for all but two of

Table 1. *Estimated trends in scissor-tailed flycatcher (*Tyrannus forficatus*) 1966–87.*

Transformation log(x+0.23)
Windsorizing value 100

Stratum	Number of routes	Estimate of slope in LOG10 scale	Doubling or half-life	Percentage change Per year	Percentage change Over 10 years
Kentucky	1[a]	0.0094	d 32	2.18	24
New Mexico	3[a]	0.0080	d 37	1.86	20
Iowa	1[a]	–0.0007	hgn[c]	–0.16	–2
Texas	109	–0.0042*[b]	h 72	–0.96	–9
Oklahoma	35	–0.0046*	h 65	–1.05	–10
Missouri	14[a]	–0.0099	h 30	–2.25	–20
Arkansas	22[a]	–0.0102*	h 29	–2.32	–21
Kansas	37[a]	–0.0178*	h 17	–4.02	–34
Louisiana	11[a]	–0.0187	h 16	–4.21	–35
3	1	0.0392	d 8	9.45	147
55	8	0.0220	d 14	5.20	66
53	16	0.0158*	d 19	3.70	44
14	1[a]	0.0094	d 31	2.18	24
32	6[a]	0.0069	d 44	1.60	17
19	21[a]	0.0067	d 45	1.55	17
81	1[a]	0.0051	d 59	1.18	12
7	18	0.0024	dgn[d]	0.55	6
5	6[a]	0.0006	dgn	0.14	1
54	12	–0.0011	hgn	–0.25	–2
33	36	–0.0039	h 77	–0.89	–9
4	25	–0.0042	h 72	–0.96	–9
6	13	–0.0076*	h 40	–1.73	–16
35	16	–0.0113*	h 26	–2.52	–23
36	1[a]	–0.0153	h 20	–3.46	–30
8	21	–0.0159*	h 19	–3.59	–31
56	9	–0.0199*	h 15	–4.47	–37
34	22	–0.0267*	h 11	–5.96	–45
Combined	233	–0.0049*	h 62	–1.12	–10.7

[a] Mean route counts are less than two, and trend may be substantially biased.
*[b] = significant trend ($P < 0.05$) based on 1,000 rerandomizations.
hgn[c] = half-life greater than 99.
dgn[d] = doubling-life greater than 99.

these States, 55 and 32, while the increases were significant for four of them 53, 7, 54, and 33. In the analysis presented in Table 1, stratum 53 was the only region which showed an overall significant increase and hence appeared different from the other strata. By separating the data into shorter time periods it is revealed that the population changes in this stratum are similar to those in other strata except that the increase over the most recent 10 years is more pronounced.

The estimates of trend for stratum 8 are similar in magnitude and direction for all time periods considered. This suggests that for this stratum calculating an overall trend line for the entire period of the survey is valid. For all other strata and all States, however, the estimates of trend are not consistent for the different time frames, which indicates that estimating the trend over the entire 22-year period of the survey is not a tenable summary of the data.

Table 2. *Estimated trends in scissor–tailed flycatcher (*Tyrannus forficatus*) for selected time periods. Trends are shown as the percentage change that would take place over a 10–year period, with the number of routes used in the analysis shown in brackets.*

Transformation log(x+0.23)
Windsorizing value 100

	Period									
Stratum	1966–83		1983–87		1966–78		1978–87		1966–87	
Kentucky	55	(1)	99	(1)	—		20	(1)	24	(1)
New Mexico	20	(3)	—		45	(2)	97	(2)	20	(3)
Iowa	7	(1)	—		51	(1)	—		2	(1)
Texas	25[a]	(108)	68[a]	(76)	49[a]	(104)	46[a]	(99)	9[a]	(109)
Oklahoma	16[a]	(35)	10	(23)	27[a]	(33)	14	(34)	10[a]	(35)
Missouri	14	(13)	16	(11)	51	(9)	24	(14)	20	(14)
Arkansas	24	(15)	44	(17)	49[a]	(14)	22	(18)	21[a]	(22)
Kansas	43[a]	(34)	14	(22)	76[a]	(34)	24	(28)	34[a]	(37)
Louisiana	62[a]	(11)	734	(4)	75[a]	(11)	192	(6)	35	(11)
3	222	(1)	981	(1)	29	(1)	76	(1)	147	(1)
55	41	(7)	23	(4)	69	(6)	272	(7)	66	(8)
53	15	(16)	99	(12)	34[a]	(16)	150[a]	(16)	44[a]	(16)
14	55	(1)	99	(1)	—		20	(1)	24	(1)
32	38	(5)	75	(3)	10	(4)	90	(4)	17	(6)
19	28	(17)	86	(19)	20	(13)	13	(21)	17	(21)
81	43	(1)	—		—		10	(1)	12	(1)
7	28[a]	(18)	174[a]	(12)	55[a]	(18)	158[a]	(14)	6	(18)
5	9	(4).	5,270[a]	(2)	30	(4)	195[a]	(2)	1	(6)
54	18[a]	(12)	76	(8)	40[a]	(11)	39[a]	(11)	2	(12)
33	21[a]	(34)	118	(26)	42[a]	(33)	14	(35)	9	(36)
4	27	(24)	6	(14)	53[a]	(24)	33[a]	(20)	9	(25)
6	27[a]	(13)	36	(8)	49[a]	(13)	32	(10)	16[a]	(13)
35	33[a]	(16)	95	(11)	39[a]	(16)	14	(15)	23[a]	(16)
36	37	(1)	—		55	(1)	—		30	(1)
8	29[a]	(21)	53	(19)	46[a]	(20)	21	(21)	31[a]	(21)
56	58[a]	(9)	1,783	(3)	60	(8)	43	(7)	37[a]	(9)
34	47[a]	(1)	48	(11)	61[a]	(20)	24	(16)	45[a]	(22)
Combined	24[a]	(221)	47	(154)	45[a]	(208)	38[a]	(202)	11[a]	(233)

[a] Significant trend ($P < 0.05$) based on 1,000 rerandomizations.

Route–regression Analysis of Scissor-tailed Flycatcher Population Trends

by

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Introduction

The Office of Migratory Bird Management of the U.S. Fish and Wildlife Service has supported the development of several computer programs for the estimation of population trends and annual indices of abundance from North American Breeding Bird Survey (BBS) data. The programs presently in use are written in FORTRAN, although alternative programs are available which are written for standard statistical packages (e.g., the SAS-based programs used to estimate trends in Robbins et al. 1986). This statistical analysis of scissor-tailed flycatcher (*Tyrannus forficatus*) population trends provides an example of the present method adopted by the U.S. Fish and Wildlife Service to estimate population trends and annual indices of abundance.

Methods

Population trends are estimated using the route regression method (Geissler and Sauer 1990). We include observers as covariables in the route regressions. The median of the bootstrapped estimates of trend from individual routes is used as the estimate of population trend in this analysis. The trend is presented as a percent change per year, which is the median trend –1 times 100 %. Statistical significance of the trend estimates (the test of the null hypothesis of no trend) is assessed using *z*-tests. Indices are estimated using the residual method (Sauer and Geissler 1990).

Population trends and annual indices of abundance are estimated for State, physiographic stratum (see Butcher 1990 for a listing of the present BBS physiographic strata), and the entire region of the survey. In addition to the trend estimates, I also present the proportion of routes in each region which had negative point estimates of trend. These proportions represent an unweighted measure of the consistency of population declines in the region. Finally, I present the average density (in number of birds recorded per BBS route) of scissor-tailed flycatchers on BBS routes within the regions.

Results and Discussion

Trend Estimates

Scissor-tailed flycatchers declined in the United States during 1967–87. Statistically significant ($P < 0.1$) declines occurred in Arkansas, Kansas, and Oklahoma, and Missouri and Texas had negative but nonsignificant point estimates of trend (Table). Point estimates of trend were also negative in 9 of the 14 physiographic strata in which scissor-tailed flycatchers occur, and three of the declines were statistically significant.

Over the entire area surveyed, the estimate of trend was –0.89 ($N = 229; P < 0.1$).

Because trend estimates are weighted by the density of birds on the route, they do not always show the same patterns as proportion of declining routes in a region. In general, though, there is a close correspondence between the two estimators of population change in a region (Table).

The relative contribution of State or physiographic stratum trends to the survey-wide trend estimate is determined by both the land area in the region and the relative density of birds in the region. Densities vary greatly among States and physiographic strata (Table), with some States (e.g., Louisiana) having extremely low densities of birds, but others (e.g., Oklahoma) having high densities. It is interesting to note that the only States with positive point estimates of population trend have low densities of scissor-tailed flycatchers, and therefore probably do not contribute greatly to the overall trend estimate.

Table. *Population trends of scissor-tailed flycatchers (*Tyrannus forficatus*) for 1967–87 for States, physiographic strata, and the entire breeding range in the United States. The estimate of trend is the median of the bootstrapped population trends for the region, and is presented as percent change per year. The significance of the trend estimate (*P, *test of* H_0*:trend = 0) is presented as * :*P < *0.1; *** :*P < *0.01. Sample size (*N*) is the number of BBS routes in the regions, Pdec is the proportion of routes in the region with declining populations, and Average is the average density of birds on routes in the region. Trends are not presented for regions with* N ≤ *2 routes.*

Region	Trend	*P*	*N*	Pdec	Average
State					
Arkansas	–6.36	***	22	0.500	1.23
Kansas	–1.79	*	36	0.611	2.09
Louisiana	1.63		11	0.545	0.66
Missouri	–1.32		14	0.357	0.38
New Mexico	6.47		3	0.000	0.34
Oklahoma	–2.01	***	35	0.629	21.90
Texas	–.29		108	0.546	18.88
Stratum					
4.	–3.56		25	0.600	6.18
5.	–0.05		6	0.500	0.04
6.	–0.01		13	0.538	13.09
7.	0.03		17	0.706	23.60
8.	–2.49	***	21	0.762	29.39
19.	–1.71		21	0.333	1.74
32.	–10.17		6	0.500	0.04
33.	0.22		36	0.528	19.22
34.	–4.52	*	22	0.545	3.20
35.	–3.47	***	15	0.667	15.05
53.	2.56		16	0.375	17.96
54.	0.24		12	0.500	29.51
55.	1.01		8	0.375	2.06
56.	–6.70		9	0.556	1.42
Breeding range					
U.S.	–0.89	*	229	0.546	10.918

Annual Indices of Abundance

Annual indices of abundance are quite variable in most of the States in which scissor-tailed flycatchers occur (Fig. 1), but a general pattern of annual indices below the predicted trend line during the mid-1970's occurs in all of the high-density States. Texas in particular shows a distinct minimum in 1977.

Indices of abundance from the entire survey (Fig. 2) indicate that scissor-tailed flycatchers declined through the early 1970's and reached minimum densities in 1978. After 1978, the population has been stable or increasing slightly, but has not reached density levels noted in the late 1960's and early 1970's. The indices from the entire survey area generally reflect the patterns of change seen in Oklahoma and Texas, where scissor-tailed flycatchers reach their highest densities.

What Factors Influence Population Changes in Scissor-tailed Flycatchers?

Robbins et al. (1986) documented the decline in scissor-tailed flycatcher populations through the mid-1970's. Here, I show that populations have been generally increasing after the low year of 1978. Over the entire time interval, however, the population still shows a slight decline, indicating that the flycatchers have not yet achieved the levels of abundance that existed during the early years of the survey.

It is difficult to explain the patterns of population change in the scissor-tailed flycatchers. The scissor-tailed flycatcher pattern of decline, then increase, is remarkably similar to the pattern of population change in several short-distance migrant and permanent resident species, such as Carolina wrens (*Thryothorus ludovicianus*), eastern bluebirds (*Sialia sialis*), and mourning doves

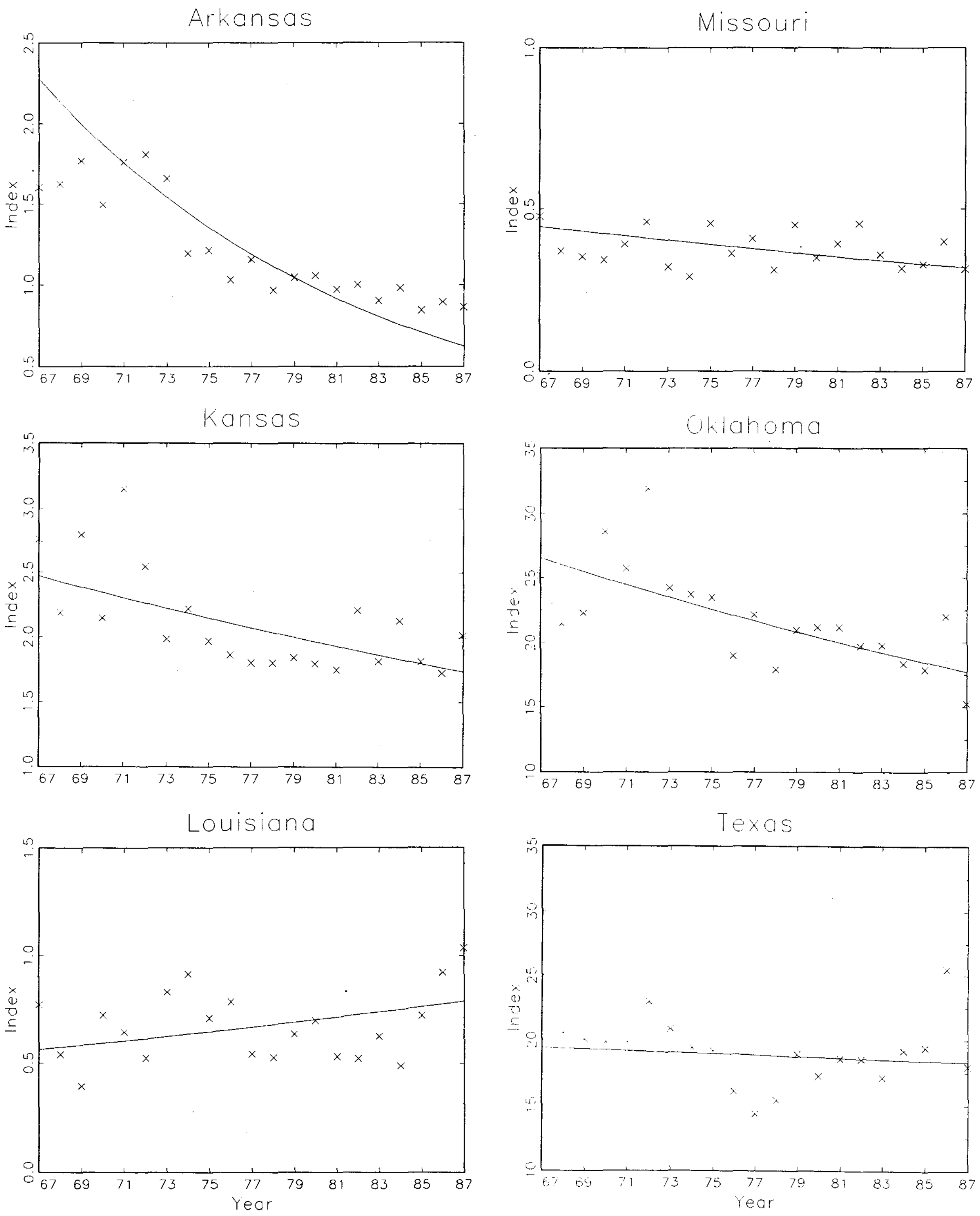

Fig. 1. Annual indices of abundance (x) and predicted trend for scissor-tailed flycatchers (*Tyrannus forficatus*) by State (excepting New Mexico, in which the species was recorded on $N = 3$ routes).

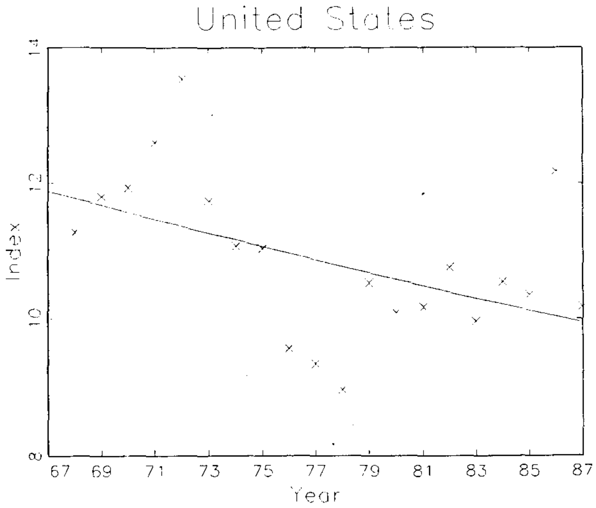

Fig. 2. Annual indices of abundance (x) and predicted trend for scissor-tailed flycatchers (*Tyrannus forficatus*) for the entire survey area in the United States.

(*Zenaida macroura*). These species apparently declined in response to a series of severe winters during the 1970's (Robbins et al. 1986). The scissor-tailed flycatcher is a neotropical migrant species, but primarily winters in open habitats and is probably not affected by the tropical deforestation that could affect forest-wintering migrants (Robbins et al. 1989). It is beyond the scope of this paper to fully examine the possible explanations for the observed population trends in scissor-tailed flycatchers. However, the route regression estimates of trend, in conjunction with annual indices of abundance, provide sufficient information for a complete analysis of scissor-tailed flycatcher population changes over any interval of interest.

Acknowledgments

I thank D. K. Dawson, M. Howe, and J. D. Nichols for reviewing this manuscript. H. C. Bourne assisted with preparing the data for analysis.

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Trends in Counts of Scissor-tailed Flycatchers Based on a Nonparametric Rank-trend Analysis

by

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Introduction

A variety of statistical methods exist for estimating trends in animal population sizes over time (e.g., Geissler and Noon 1981; Gerrodette 1987; Sauer 1990). Many of these trend methods rely on regression type procedures. While route-regression trend analyses procedures provide information on the significance of a trend (Geissler and Noon 1981), they also provide an estimate of the annual change in counts over the time period. In some instances, nonparametric methods may be useful for determining trends over time, especially if data were obtained in the form of ranks or if the assumptions of route-regression methods are not valid. These tests are usually variations of the sign test (Conover 1980). One nonparametric time-trend estimation method was developed by Lehmann (1975). This method has been expanded to allow for multiple counts in a given time period, and is thus similar to some regression procedures where counts from the same time period can be combined to estimate a trend.

I compare results from a nonparametric rank-trend analysis of scissor-tailed flycatcher (*Tyrannus forficatus*) Breeding Bird Survey data with those obtained from the standard route-regression trend analysis of the same data (Sauer 1990). Empirical comparisons of the results obtained from these methods is useful so that the value and limitations of the less commonly used nonparametric method are identified. In this way, biologists may be better able to choose the appropriate method for their application.

Methods

Breeding Bird Survey data for scissor-tailed flycatchers were used in this analysis. A nonparametric rank-trend analysis statistical procedure was applied to the data. This method was described in Titus et al. (1990) and was based on a two-tailed expansion of the test statistic developed in Lehmann (1975). The nonparametric rank-trend analysis program was developed using the Statistical Analysis System (SAS 1985, 1987) by D. Jacobs. This program tested for a trend in each of the 230 routes separately; it pooled routes within States to determine an overall trend for each State, and finally, all routes were pooled to determine a single overall trend estimate. Results of the nonparametric method were expressed as an increasing or decreasing trend over time, along with an associated level of significance.

Results and Discussion

Based on the nonparametric rank-trend analysis, scissor-tailed flycatchers were declining throughout their range as a whole ($P = 0.0004$), in Kansas ($P = 0.0001$), and in Oklahoma ($P = 0.026$; Table 1). Only in Missouri was there a nonsignificant increase in the trend estimate.

Comparison of Methods

The route-regression and nonparametric methods resulted in similar interpretations except for counts from Arkansas, where the nonparametric method detected no trend while the route regression method

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Table 1. *Population trends of scissor-tailed flycatchers* (Tyrannus forficatus) *from 1967–87 by State, based on nonparametric rank-trend and route regression trend analyses.*

		Nonparametric method			Route-regression method			
State	*N*	Trend	*P*	Pdec[a]	Trend	Significance[b]	Pdec	Comment
Arkansas	22	decline	0.402	0.36	decline	***	0.50	results very different; rank test not significant while route regression highly significant
Kansas	37	decline	0.001	0.76	decline	*	0.61	results similar between methods
Louisiana	11	decline	0.254	0.91	increase	NS	0.55	results similar; both insignificant, although trends differ
Missouri	14	increase	0.191	0.36	decline	NS	0.36	results similar; both insignificant, although trends differ
New Mexico	3	decline	0.485	0.67	increase	NS	0.00	results similar; both insignificant, although trends differ
Oklahoma	35	decline	0.026	0.63	decline	***	0.63	results similar between methods
Texas	108	decline	0.345	0.58	decline	NS	0.63	results similar between methods
U.S.	230	decline	<0.001	0.60	decline	*	0.55	results similar between methods

[a] Proportion of routes that had a declining trend.

[b] Significance of route-regression trend estimate; * = $P < 0.1$; *** = $P < 0.01$; NS = $P > 0.1$.

detected a significant decline (Table 1). This discrepancy was likely due to the unbalanced nature of the Arkansas data set. Data were available from 22 routes in Arkansas. One route had high counts (10–20 birds per route per year), a few routes had moderate to low counts (2–8 birds per route per year), and on most other routes observers counted no scissor-tailed flycatchers in a given year. The single route with the highest counts declined over this time, and the route-regression method weighted this route more heavily in the analysis. Thus, route-regression (Geissler and Sauer 1990) can adjust for extreme differences in counts among routes, while the nonparametric method contains no weighting function.

This example bears out the important difference that a weighting function can have on the future data interpretation. Weighting may not be appropriate in some situations, and biologists need to understand how different statistical techniques might influence their interpretations. The nonparametric method contained no weighting function, although one could be incorporated into the statistical procedure. In the context of avian surveys, the nonparametric method treats each area equally and is not influenced by the population size of any survey location.

The scissor-tailed flycatcher data set contained many routes with zeros. This resulted in many tied ranks, an unfavorable situation for nonparametric procedures that evaluate ranks. The influence of ties may be to make the results more significant because of the long length of consecutive zero ties (Siegel 1956). Even though the procedure developed in Titus et al. (1990) accounted for tied ranks, the scissor-tailed flycatcher data set may be better analyzed by a method that is less sensitive to the many zero counts. Inspection of the proportion of individual routes where counts were declining indicated general agreement among methods (Table 1). Overall, 5% more of the individual routes had declining trends in counts based on the nonparametric method. This higher proportion of routes which were declining, combined with the sample size dependent variance estimate of the nonparametric method likely led to the more highly significant overall trend when compared with a the route-regression method.

Conclusion

The nonparametric rank-trend analysis method is most appropriate in situations where the data contain few zeros (or ties), and the counts may be estimates rather than exact numbers, so an analysis based upon ranks may be appropriate. The method provides less information than a complete route-regression analysis and annual indices of abundance (Sauer 1990). However, if one desires information about an increase or decrease in the population of interest, and they cannot meet all the assumptions of regression methods, the nonparametric method is appropriate.

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