CHAPTER I

INTRODUCTION

BACKGROUND

The purpose of this chapter is to provide the reader with a general background to the Key deer and its environment. This chapter will begin by describing the Key deer, its distribution, current status of the population, and conservation measures currently being used in the Key deer's recovery. Next, a description of the study area, including geology, vegetation types, and spatial patterns within the Key deer range, will be presented. Finally, a review of the research objectives for this dissertation will conclude this chapter. Commonly used acronyms and scientific names for plants and animals used throughout this dissertation are in Table 1.1.

Key Deer

The endangered Key deer, the smallest sub-species of white-tailed deer in the United States, are endemic to the Florida Keys on the southern end of peninsular Florida (Hardin et al. 1984). In comparison to other white-tailed deer, Key deer are smaller with an average shoulder height between 61-81 cm, and average weights of 29 kg (maximum 45 kg) and 38 kg (maximum 66 kg) for females and males, respectively (R. R. Lopez, TAMU, unpublished data).

Due to uncontrolled hunting, Key deer numbers were estimated to be less than 50 in the 1940's (Hardin et al. 1984, Chapter IV). A famous cartoon (Fig. 1.1, Hardin et al. 1984) by Jay "Ding" Darling, cartoonist, conservationist, and chief of the United States Bureau of Biological Survey (predecessor to USFWS), drew national attention to the Key deer's plight, and was instrumental in the drafting of legislation to protect the deer. Early hunting practices used by poachers included burning islands and driving deer into the water were they were clubbed or shot to death. Increased law enforcement and the establishment of the NKDR in 1957 provided protection for the deer and its habitat. Consequently, the deer population grew to an estimated 300-400 animals by 1974 (Klimstra et al. 1974). Currently, Key deer occupy 20-25 islands within the boundaries of the NKDR with approximately 75% of the deer occupying 2 islands – Big Pine and No Name keys (Folk 1991, Chapter IV).

Format and style follows The Journal of Wildlife Management.

Table 1.1. Index to commonly used acronyms, animal names (common and scientific), and plant names (common and scientific) presented in dissertation.

Common name/acronym	Scientific name/description
Acronyms	
BPK	Big Pine Key
BW	buttonwood
DCA	Florida Department of Community Affairs
DV	developed
ESA	Endangered Species Act of 1973
FDOT	Florida Department of Transportation
FM	freshwater marsh
GIS	geographical information system
HCP	habitat conservation plan
HM	hammock
LCI	lower confidence interval
MG	mangrove
NBPK	north Big Pine Key
NKDR	National Key Deer Refuge
NNK	No Name Key
PL	pineland
PVA	population viability analysis
SBPK	south Big Pine Key
SD	standard deviation
SE	standard error
TAMU	Texas A&M University
TNC	The Nature Conservancy
UCI	upper confidence interval
USFWS	United States Fish and Wildlife Service
Animals	
Key deer	*Odocoileus virginanus clavium*

Table 1.1. Continued.

Common name/acronym	Scientific name/description
turkey vultures	*Cathartes aura*
Plants	
Australian pine	*Casuarina equisetifolia*
black mangrove	*Avicennia germinans*
blackbead	*Pithecellobium keyense*
blacktorch	*Erithalis fruticosa*
blolly	*Pisonia discolor*
Brazilian pepper	*Schinus terebinthifolia*
broom sedge	*Andropogon glomeratus*
buttonwood	*Conocarpus erectus*
Christmas berry	*Lycium carolinianum*
cordgrass	*Spartina spp.*
dropseed	*Sporobolus spp.*
false foxglove	*Agalinis spp.*
glasswort	*Salicornia spp.*
gumbo limbo	*Bursera simaruba*
Indian grass	*Sorchastrum spp.*
Jamaican dogwood	*Piscidia piscipula*
Joewood	*Jacquinnia keyensis*
key grass	*Monanthochoe littoralis*
Keys thatch palm	*Thrinax morrisii*
leather fern	*Acrostichum spp.*
locustberry	*Bursonima lucida*
love vine	*Cuscuta spp.*
mayten	*Maytenus phyllanthoides*
pigeon plum	*Coccoloba diversifolia*
pineland croton	*Croton linearis*
poisonwood	*Metopium toxiferum*

Table 1.1. Continued.

Common name/acronym	Scientific name/description
red mangrove	*Rhizophora mangle*
saffron plum	*Bumelia celastrina*
salt grass	*Distichlis spicata*
saw palmetto	*Serenoa repens*
saw sedge	*Cyperus ligularis*
sawgrass	*Cladium jamaicense*
sea daisy	*Borrichia arborescens*
sea grape	*Coccoloba uvifera*
sea oxeye	*Borrichia frutescens*
sea purslane	*Sesuvium spp.*
silver palm	*Coccothrinax argentata*
slash pine	*Pinus elliottii*
stoppers	*Eugenia spp.*
white mangrove	*Lagyncularia racemosa*
white-top sedge	*Dichromen floridensis*
wild dilly	*Manilkara bahamensis*
yellow root	*Morinda royoc*

Fig. 1.1. Cartoon by Jay "Ding" Darling that was instrumental in providing protection to the Key deer, 1934 (Hardin et al. 1984).

Habitat Conservation Planning

Klimstra et al. (1974) and Folk (1991) reported urban development, habitat fragmentation, and the taming of deer as a threats to the Key deer's recovery. Between 1968-98 the human population on Big Pine and No Name increased nearly 10-fold (Monroe County Growth Management 1992). Increases in urban development is of particular concern because road mortality accounts for the majority of the total deer mortality (Hardin 1974, Folk 1991). Over half of all road mortalities occur on United States Highway 1 (US 1), the only road linking the Keys to the mainland (Folk 1991, Chapter II). Safe and expedient evacuation during hurricanes depends on the level of service or traffic levels on US 1. In 1995, Monroe County authorities imposed a building moratorium due to the inadequate level of service on the US 1 segment servicing Big Pine and No Name keys. In an effort to improve the level of service and lift the building moratorium, highway improvements such as intersection widening and/or adding a third lane northbound (traffic direction towards mainland) have been proposed and are being evaluated (Calvo 1996, C. Owens, FDOT, personal communication).

Because additional traffic and development on Big Pine and No Name keys might result in an "incidental take" of Key deer, highway improvements could be permitted with the initiation and approval of a HCP. Legislators established the ESA of 1973 to protect species and their habitat. In 1982, the ESA was amended to authorize incidental taking of any endangered species by landowners and non-federal entities provided they develop an HCP (ESA, Section 10a, 16 U.S.C. §1539a). In 1998, a planning process began with FDOT, Monroe County, and DCA representatives to draft and submit a regional Key deer HCP to USFWS. A PVA, a method used to evaluate population threats in terms of extinction risk or decline based on computer simulation models, is an integral part of this HCP (Boyce 1992, Burgman et al. 1993, Chapter VII). Current demographic estimates (e.g., survival, reproduction, density) are required for its development, and are not available from previous studies.

STUDY AREA

Deer Metapopulation

According to Gilpin and Hanski (1991), a collection of discrete or local animal populations is a metapopulation. In metapopulation theory, suitable habitats are "islands" in a "sea" of unsuitable habitats (Gilpin and Hanski 1991). This definition is well suited in describing the Key deer population, where local deer populations occupy actual islands. Klimstra et al. (1974) identified 17 islands and/or complexes (group of islands close to each other where deer dispersal is relatively unrestricted) in their study: West Summerland, Newfound Harbor, Bahia Honda, Johnson Complex, Annette Complex, Little Torch, Howe, Ramrod, Little Pine Complex, Middle Torch, Summerland, No Name, Knockemdown, Big Torch, Cudjoe, Sugarloaf, and Big Pine keys. In this study, Key deer or their sign (tracks, pellets) were observed on all islands or complexes except Summerland and Knockemdown (island was not surveyed due to limited access).

Geology and Soils

The Florida Keys is comprised of 2 types of surface rock from the Pleistocene age formations: (1) oolitic Miami limestone, and (2) Key Largo limestone. The majority of the Key deer range consists primarily of the former (Hardin et al. 1984, Folk 1991). Little topsoil is present except in areas where humus has accumulated (Folk 1991). According to Hardin et al. (1984), Key deer were isolated from the mainland 6-12 thousand years ago when the last glaciers

melted and sea levels rose, resulting in the creation of these islands. For the past thousands of years, Key deer have adapted to this unique marine environment (Folk 1991).

Vegetation Types

Native flora of the Lower Keys is primarily West Indian in origin (Dickson 1955). Typically, island areas near sea level (maritime zones) are comprised of red, black, and white mangroves, as well as buttonwood forests. As elevation increases, these maritime zones transition into hardwood hammocks and eventually into pineland forests intolerant of salt water (Dickson 1955, Folk 1991). Freshwater marshes are lowlands or basins surrounded either by higher upland forests or between upland areas and transition zones. Urban development has occurred in many of these native areas in the last several decades, particularly mangrove and buttonwood areas in earlier years (Chapter III). Silvy (1975) and Hardin (1974) described 6 vegetation types: pinelands (PL), hammock (HM), developed (DV), freshwater marsh (FM, referred to as hardwood in their studies), buttonwood (BW), and mangrove (MG). A description of each of these vegetation types and representative plant species follow:

Mangrove.—Mangrove forests are dense, low forests occurring along flat, maritime zones (Fig. 1.2). Average elevation is 0-1 m above mean sea level (Folk 1991). Dominant plants are red, black, and white mangroves. Other plants associated with mangrove forests include glasswort, salt grass, key grass, and sea daisy. In general, vascular plant diversity of mangroves increases with increasing elevation (Dickson 1955, Silvy 1975, Florida Natural Areas Inventory 1990, Folk 1991).

Buttonwood.—Transitional areas between mangrove forests and upland forests consist of buttonwood prairie, salt marsh, and open scrub (Dickson 1955, Silvy 1975, Folk 1991, Fig. 1.3). Average elevation is 0.5-1 m above mean sea level (Folk 1991). In buttonwood forests, most plant species are resistant to salt water although these areas are not tidally-influenced (Silvy 1975). Plant species near the mangrove zones include red mangrove, black mangrove, white mangrove, saltwort, and glasswort. With increasing elevation, these plants are replaced with buttonwood, joewood, wild dilly, mayten, blacktorch, saffron plum, dropseed, key grass, sea oxeye, cordgrass, Christmas berry, and sea purslane (Dickson 1955, Silvy 1975, Florida Natural Areas Inventory 1990, Folk 1991).

Freshwater Marsh.— Freshwater marshes are lowland areas or basins either surrounded by higher upland forests or between upland areas and transition zones (Fig. 1.4). Average elevation for freshwater marshes is 1-2 m above mean sea level, and they can vary in size from 1

ha to greater than 100 ha (Folk 1991). Plant species are similar to hammocks or pinelands, with the exception that standing freshwater levels are maintained for extended periods during the year. As a result, many wetland species such as sawgrass, buttonwood, red mangrove, saw sedge, white-top sedge, leather fern, false foxglove, and broom sedge are found in these areas (Dickson 1955, Silvy 1975, Florida Natural Areas Inventory 1990, Folk 1991).

Hammock.—Hammocks are upland hardwood forests characterized by broad-leaf evergreen trees (Fig. 1.5). Plant diversity is high, and these areas support many plants of West Indian origin including gumbo limbo, Jamaican dogwood, poisonwood, pigeon plum, blolly, stoppers, sea grape, buttonwood, wild dilly, and saffron plum (Folk 1991). Average elevation is 2-3 m above mean sea level with areas rarely effected by tides except during extreme weather events such a hurricanes (Dickson 1955, Silvy 1975, Florida Natural Areas Inventory 1990, Folk 1991).

Pineland.—Pinelands consist of an open canopy of slash pines with a patchy understory/groundcover of tropical and temperate shrubs, palms, grasses, and herbs (Florida Natural Areas Inventory 1990, Folk 1991). Historically, natural fires maintained these areas. Average elevation is 2-3 m above mean sea level with plant species being very intolerant of salt-water intrusion (Fig. 1.6). Plants associated with pinelands include blackbead, saw palmetto, Keys thatch palm, silver palm, Indian grass, Christmas berry, pineland croton, yellow root, love vine, and locustberry. Hammocks, pinelands, and freshwater marshes all are important in providing freshwater resources in the form of natural waterholes to Key deer (Dickson 1955, Silvy 1975, Florida Natural Areas Inventory 1990, Folk 1991).

Developed.— Many native vegetation types have been developed for human use in the last several decades (Folk 1991). Historically, many of these areas were dredged and filled in the late 1940's through the 1970's (Fig. 1.7, Chapter III). In some cases, invasive exotic plants such as Australian pine and Brazilian pepper are abundant on these scarified or disturbed sites and threaten neighboring native areas (USFWS 1999).

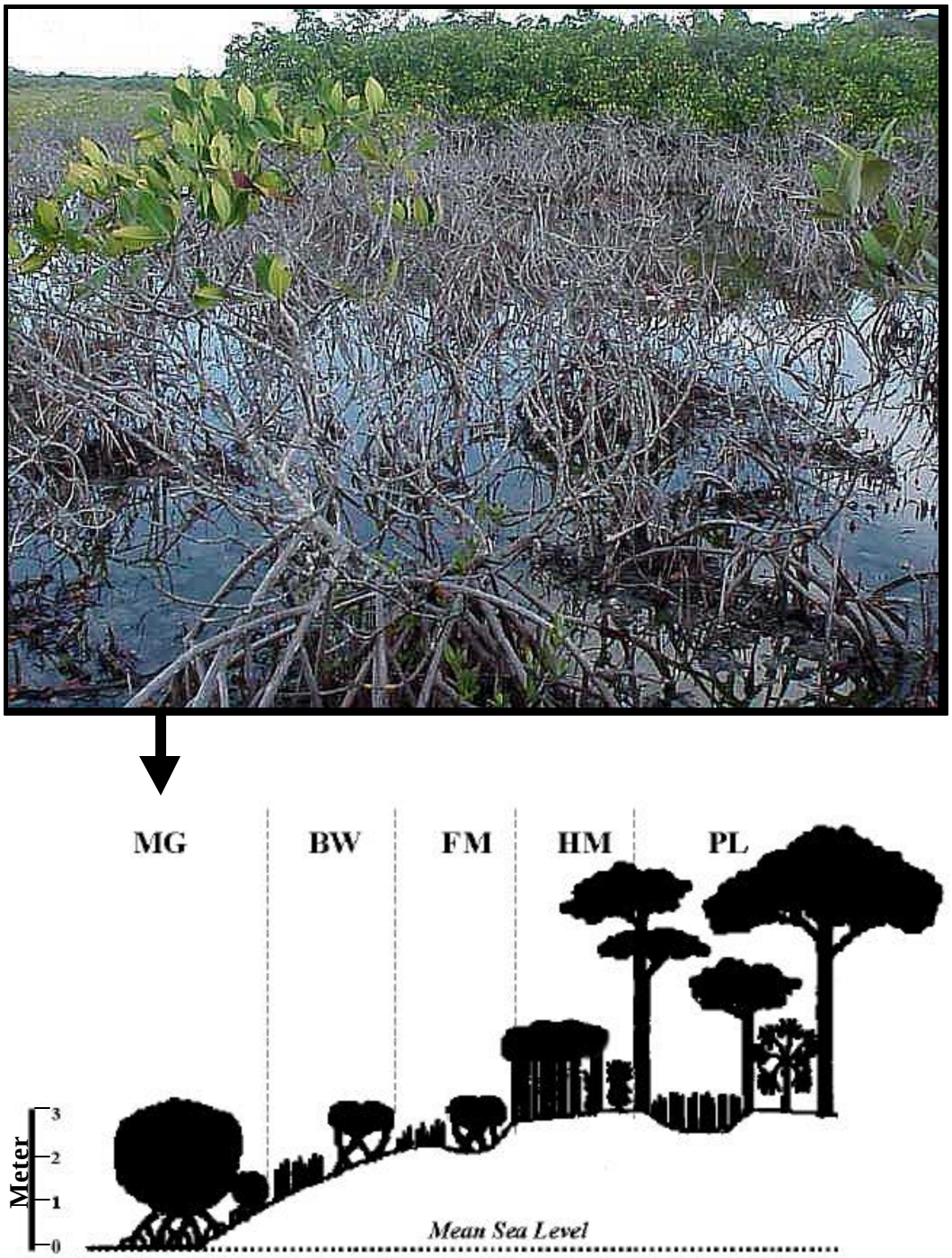


Fig. 1.2. Mangrove forest (picture) and location along vegetation transition (elevation).

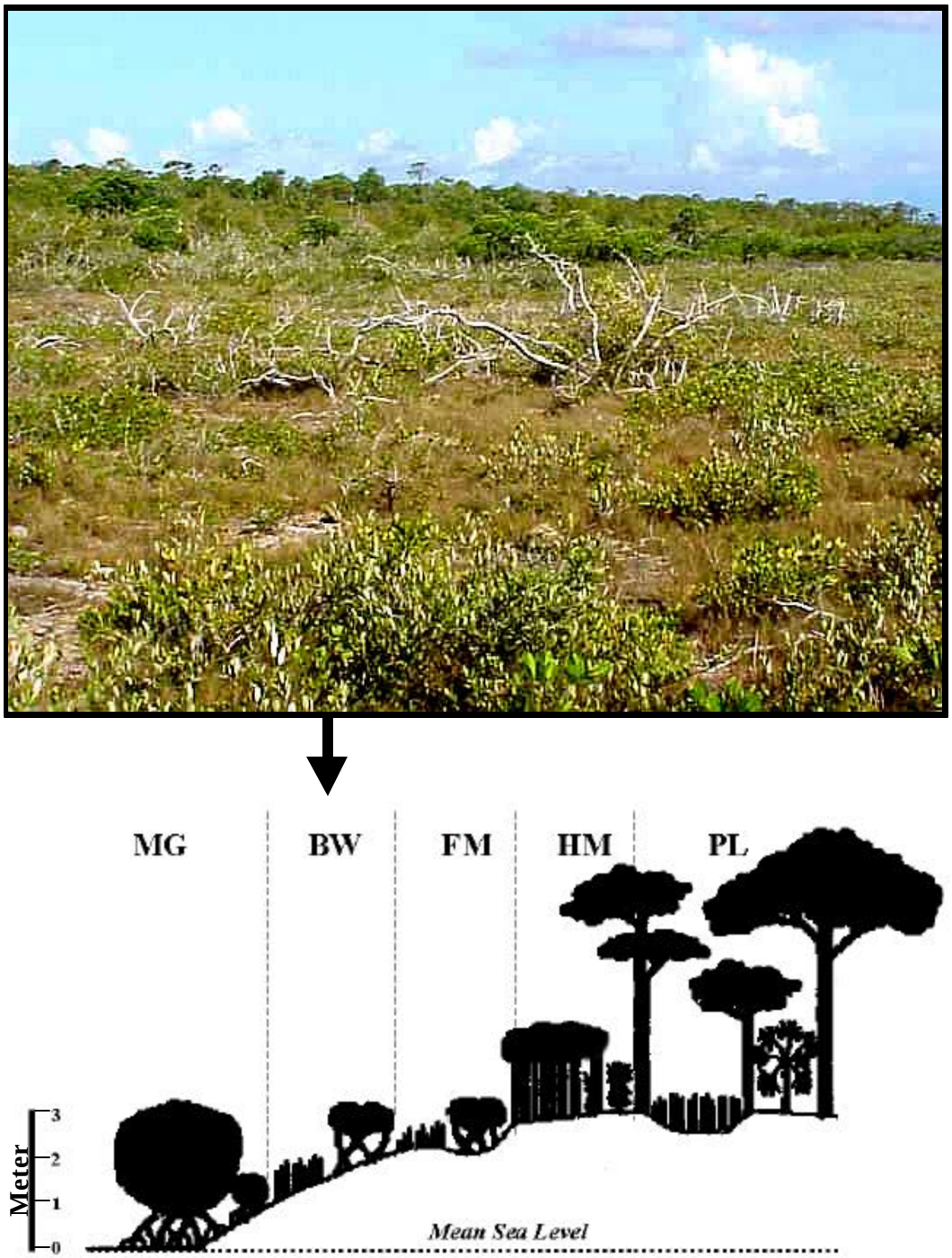


Fig. 1.3. Buttonwood forest (picture) and location along vegetation transition (elevation).

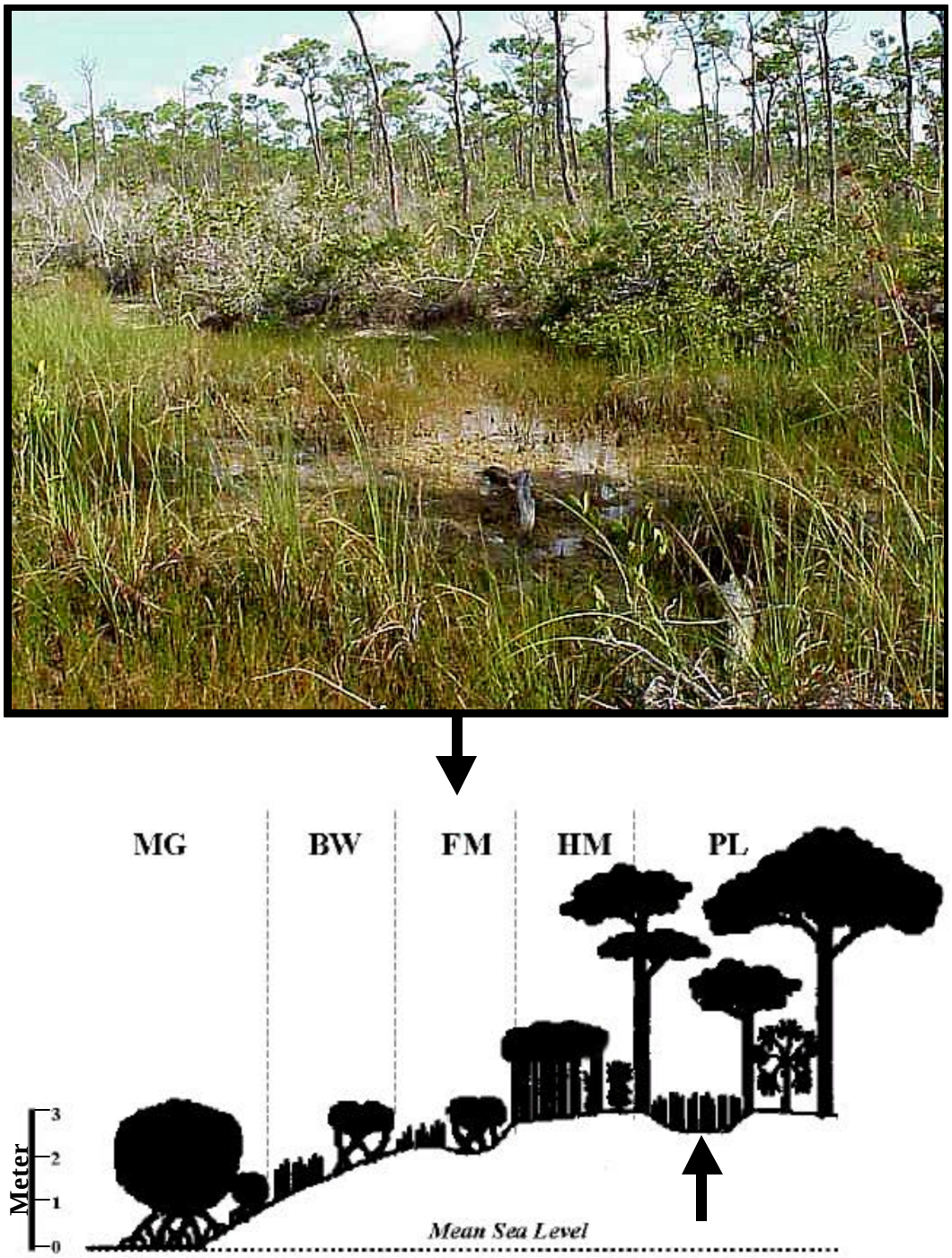


Fig. 1.4. Freshwater marsh (picture) and location along vegetation transition (elevation).

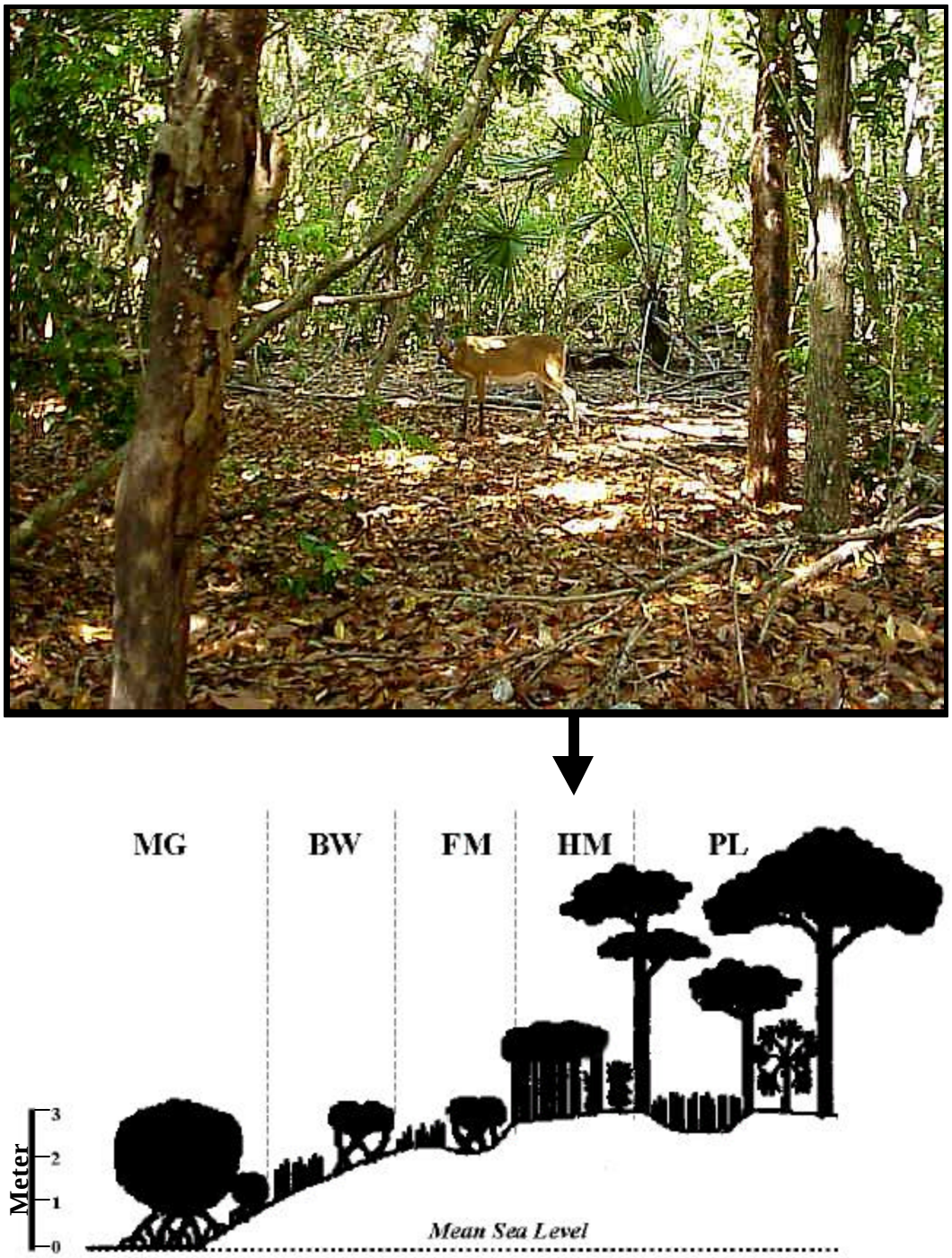


Fig. 1.5. Hammock (picture) and location along vegetation transition (elevation).

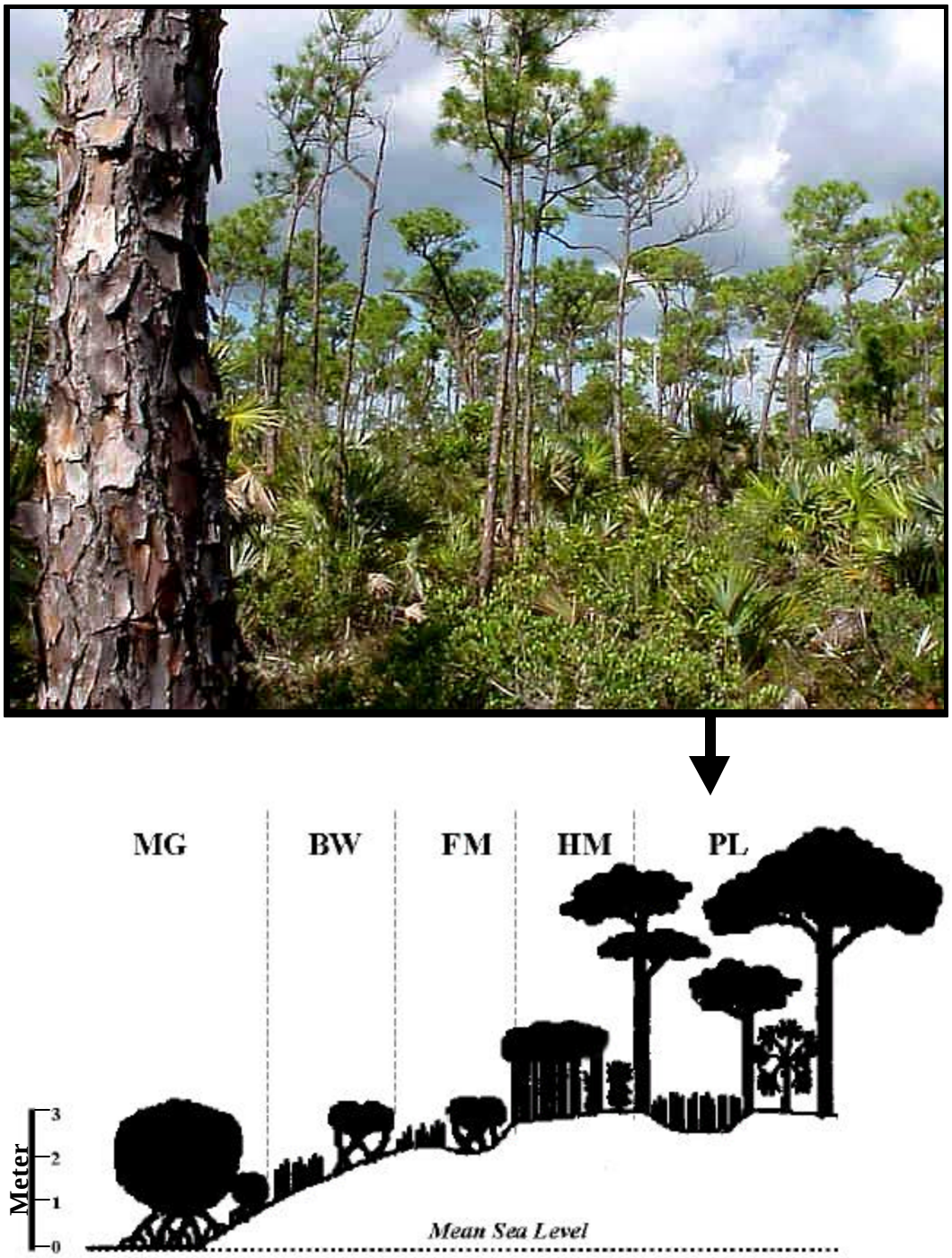


Fig. 1.6. Pineland (picture) and location along vegetation transition (elevation).

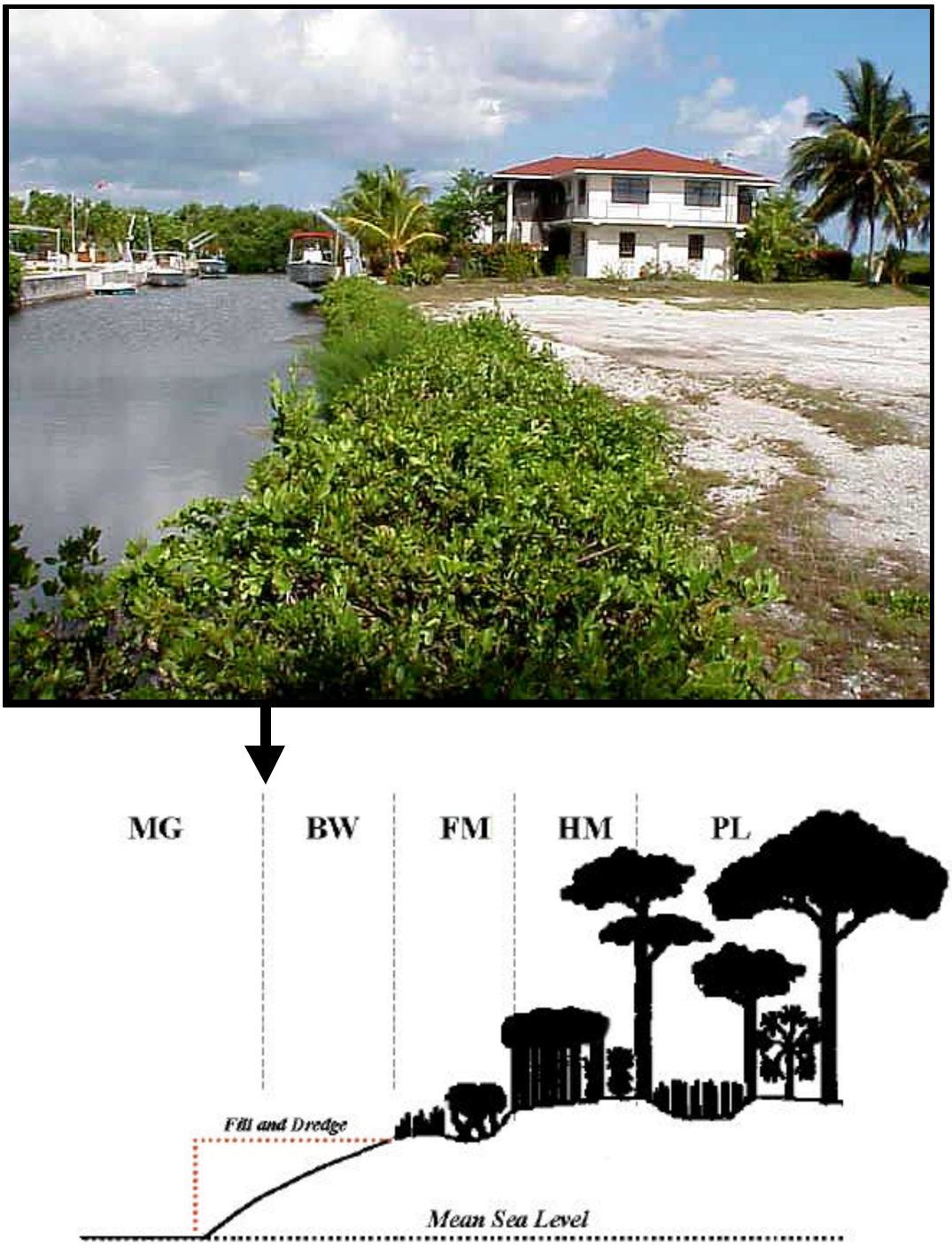


Fig. 1.7. Development (picture) and location along vegetation transition (elevation).

Spatial Patterns

Seventeen local Key deer populations identified by Klimstra et al. (1974) were used to summarize vegetation, ownership, freshwater, and development patterns within the Key deer range (Fig. 1.8). The total landmass occupied by Key deer is 9,835 ha, with islands or complexes ranging in size from 45-2,522 ha. Big Pine Key is by far the largest island (Table 1.2, Fig. 1.8).

Vegetation.—Approximately 61% of the total area within the Key deer range is comprised of tidal wetlands (mangrove, buttonwood, Table 1.2, Fig. 1.9). Tidal wetlands are reported to be marginal deer habitat (Silvy 1975, Chapter III), thus, islands with substantial uplands would be expected to support a greater number of deer. For example, Big Pine Key supports the highest deer population, and has the greatest amount of uplands in comparison to other island populations (Table 1.2, Chapter IV). Conversely, Cudjoe and Sugarloaf are large islands, however, the majority of the areas are tidal wetlands. Estimated deer numbers on these 2 islands are less than 20 animals.

Ownership.—Approximately 63% of the total area within the Key deer range is under public ownership (federal, state, or county, Table 1.3, Fig. 1.10). In reviewing ownership patterns within the core area of the Key deer herd (Big Pine and No Name keys), public lands consist of 65-75% of the total area (Table 1.3).

Freshwater.—Previous studies reported that freshwater in the form of natural waterholes are important for Key deer (Klimstra et al. 1974, Silvy 1975). Forty-six percent of permanent waterholes (n = 276) within the Key deer range are on Big Pine Key (Table 1.4, Fig. 1.11). Approximately 86% of freshwater holes were found in areas (pinelands, hammock, freshwater marsh) protected from normal tidal fluctuations (Table 1.4). This suggests that islands with significant upland vegetation, such as Big Pine Key, are particularly important to the overall viability of the deer herd due to the abundant amount of freshwater resources.

Development.—Since 1950, construction within the deer range includes nearly 6,000 homes and/or businesses (Table 1.5, Fig. 1.12), with the greatest amount of development occurring on Big Pine Key (44%). Folk (1991) found fencing had a negative impact on Key deer due to habitat loss, habitat fragmentation, and threat of entanglement. Nearly a third of developed areas (93 ha or 30%) on Big Pine and No Name keys have been completely fenced and deemed unavailable for deer use.

RESEARCH OBJECTIVES

The overall study objective was to evaluate the impacts of urban development on the demographics of the Key deer herd. This information will facilitate the continued management and recovery of the Key deer population, identify areas in management and research that need improvement, and aid in the implementation of an HCP for the Key deer. Six chapters in this dissertation address these objectives. The chapters are:

1. Survival, mortality, and life expectancy (Chapter II).
2. Habitat use patterns and vegetation changes (Chapter III).
3. Population density and structure (Chapter IV).
4. Ranges and dispersal patterns (Chapter V).
5. Hurricane impacts (Chapter VI).
6. Demographic and spatially structured population model (Chapter VII).

A final chapter will discuss management and research implications from research findings, and propose future recovery actions for the Key deer. Chapters are independent papers, and a certain amount of repetition in material presented should be expected.

Table 1.2. Distribution of vegetation types[a] (%) by island complex within the Key deer range, 2000.

	%						Area
Island Complex	BW	MG	HM	FM	PL	DV	(ha)
West Summerland	2	36	16	0	0	46	45
Newfound Harbor	10	67	18	0	0	5	76
Bahia Honda	12	58	11	0	0	19	153
Johnson Complex	25	69	5	1	0	0	154
Annette Complex	15	83	2	0	0	0	222
Little Torch	21	33	16	1	0	29	305
Howe	17	72	11	0	0	0	373
Ramrod	15	31	26	5	0	23	374
Little Pine Complex	19	52	15	1	13	0	381
Middle Torch	27	39	27	5	0	2	410
Summerland	22	40	10	0	0	28	436
No Name	15	33	34	1	10	7	459
Knockemdown Complex	22	64	12	2	0	0	582
Big Torch	23	50	17	7	0	3	626
Cudjoe	19	50	8	0	7	16	1,319
Sugarloaf	22	48	19	2	2	7	1,399
Big Pine	11	24	9	9	23	24	2,522
Total	18	43	3	4	8	14	9,836

[a]PL = pineland, HM = hammock, DV = developed, FM = freshwater marsh, BW = buttonwood, and MG = mangrove.

Table 1.3. Distribution of ownership patterns (%) by island complex within the Key deer range, 2000.

	%							Area
Name	USA[a]	FL	MC	ML	DV	UDV	TNC	(ha)
West Summerland	0	0	0	0	78	22	0	45
Newfound Harbor	0	0	0	0	73	27	0	73
Bahia Honda	0	100	0	0	0	0	0	153
Johnson Complex	100	0	0	0	0	0	0	154
Annette Complex	100	0	0	0	0	0	0	221
Little Torch	0	7	6	0	21	39	27	287
Howe	100	0	0	0	0	0	0	373
Ramrod	0	6	5	0	14	75	0	373
Little Pine Complex	100	0	0	0	0	0	0	381
Middle Torch	12	23	13	2	4	46	0	383
Summerland	0	9	21	0	19	51	0	399
No Name	71	3	2	0	5	19	0	469
Knockemdown	67	2	0	0	12	19	0	582
Big Torch	59	12	6	0	6	17	0	597
Cudjoe	56	4	6	0	12	22	0	1,219
Sugarloaf	35	12	2	0	7	43	1	1,395
Big Pine	50	12	2	2	13	20	1	2,340
Total	49	10	4	0	10	26	1	9,444

[a]USA = federal, FL = Florida, MC = Monroe County, ML = municipality, DV = developed, UDV = undeveloped, and TNC = The Nature Conservancy.

Table 1.4. Distribution of permanent freshwater sources (%) by island complex and vegetation type [a] within the Key deer range, 2000.

	%						
Island Complex	BW	MG	HM	FM	PL	DV	*n*
West Summerland	0	0	0	0	0	0	0
Newfound Harbor	0	0	0	0	0	0	0
Bahia Honda	0	0	0	0	0	0	0
Johnson Complex	33	0	67	0	0	0	3
Annette Complex	0	0	100	0	0	0	1
Little Torch	0	0	25	75	0	0	4
Howe	0	0	100	0	0	0	10
Ramrod	6	29	24	35	0	6	17
Little Pine Complex	0	0	63	15	22	0	27
Middle Torch	8	0	38	54	0	0	13
Summerland	0	100	0	0	0	0	2
No Name	0	6	50	31	13	0	16
Knockemdown Complex	19	0	37	44	0	0	16
Big Torch	14	0	43	43	0	0	7
Cudjoe	19	6	69	0	0	6	16
Sugarloaf	0	0	44	0	56	0	18
Big Pine	3	1	17	32	36	11	126
Total	5	4	36	27	23	5	276

[a]PL = pineland, HM = hammock, DV = developed, FM = freshwater marsh, BW = buttonwood, and MG = mangrove.

Table 1.5. Distribution of development by island complex within the Key deer range, 2000.

Name	Houses (*n*)	%
Knockemdown Complex	11	0.19
Middle Torch	13	0.22
Newfound Harbor	18	0.30
No Name	42	0.71
Big Torch	43	0.73
Sugarloaf	252	4.25
Ramrod	416	7.02
Summerland	628	10.60
Little Torch	652	11.01
Cudjoe	1,259	21.26
Big Pine	2,589	43.71
Total	5,923	100.00

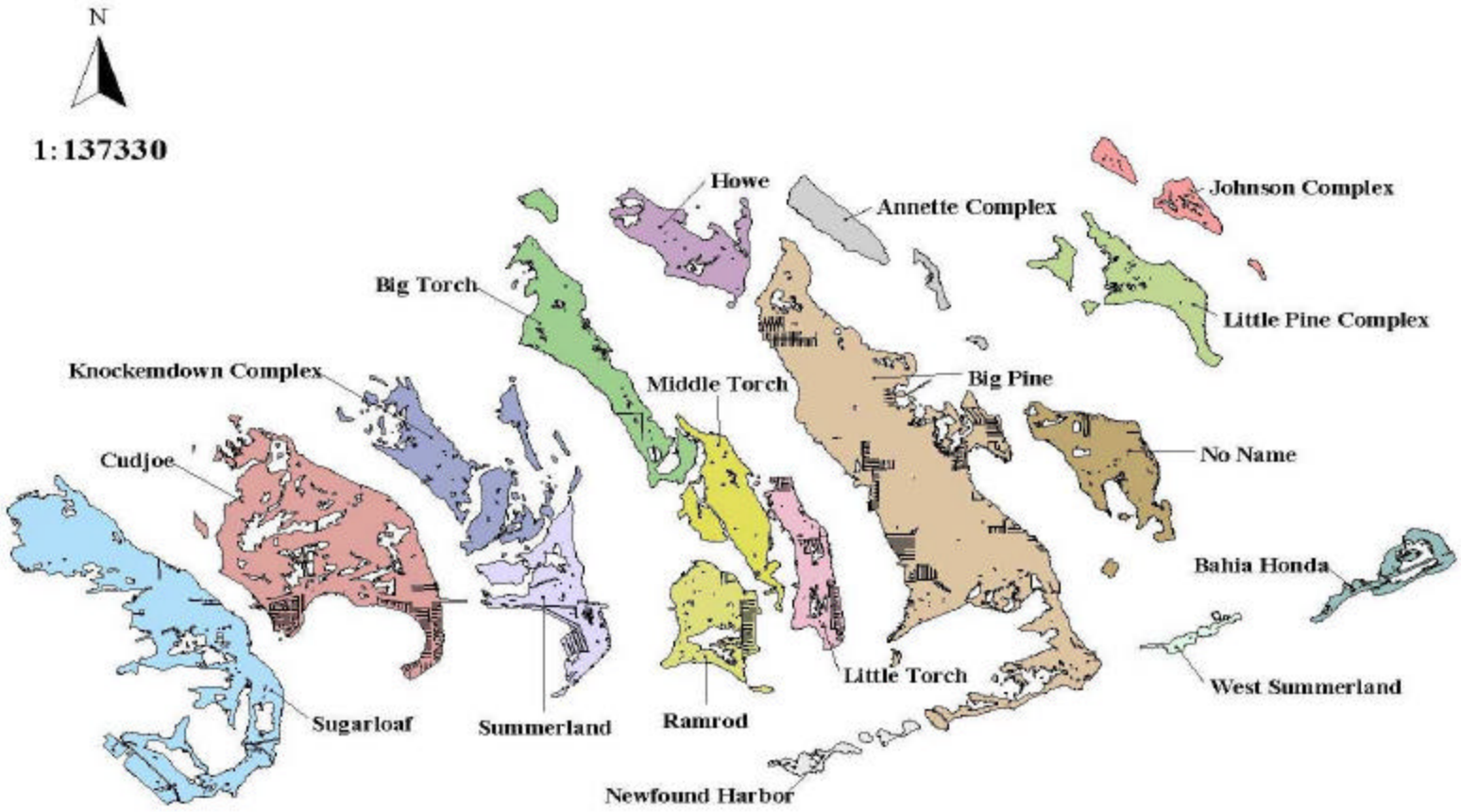


Fig. 1.1. Metapopulation dynamics of the endangered Florida Key deer.

Fig. 1.8. The endangered Florida Key deer metapopulation.

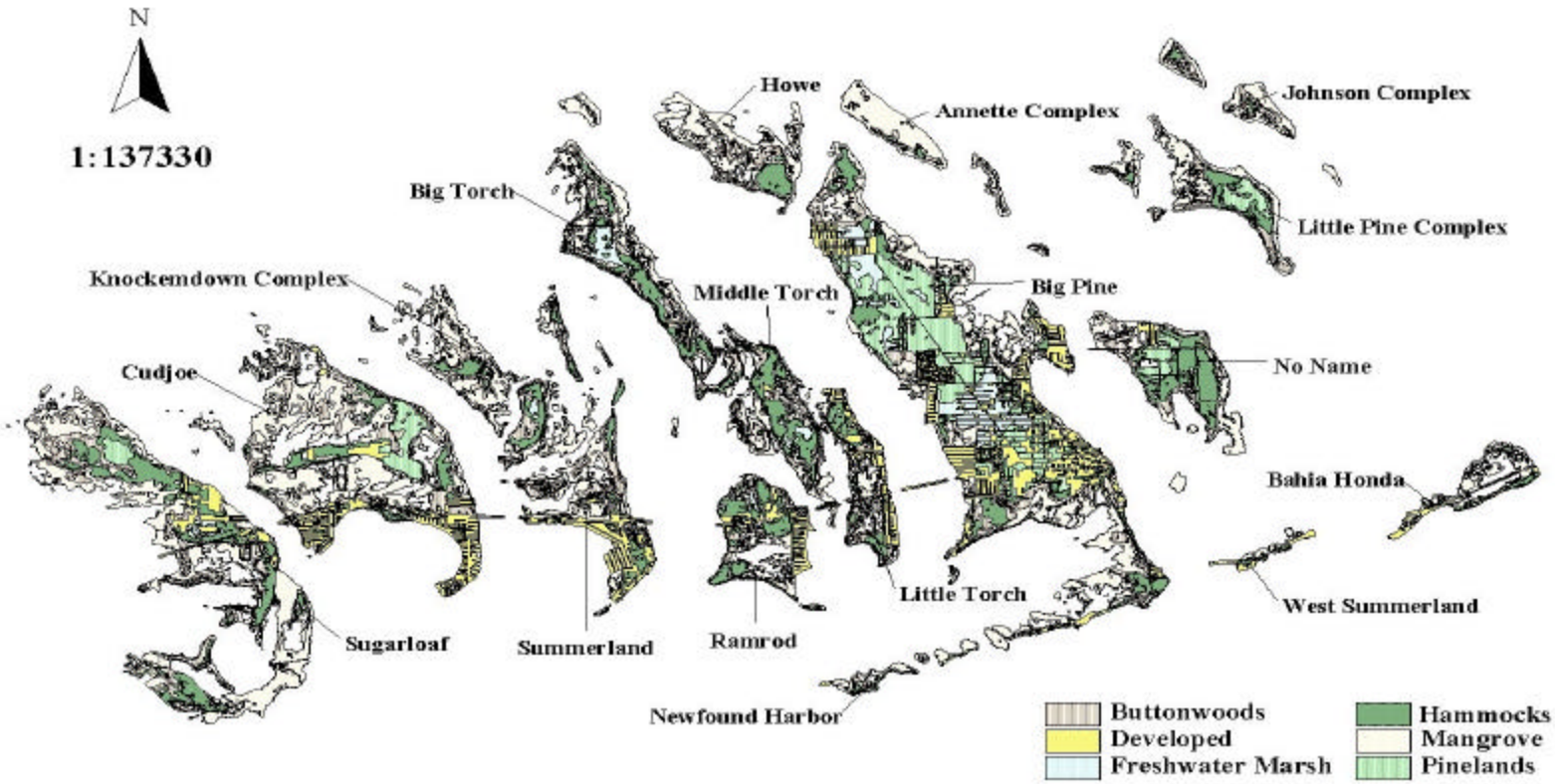


Fig. 1.2. Vegetation types within the range of the Florida Key deer.

Fig. 1.9. Vegetation types within the range of the Florida Key deer.

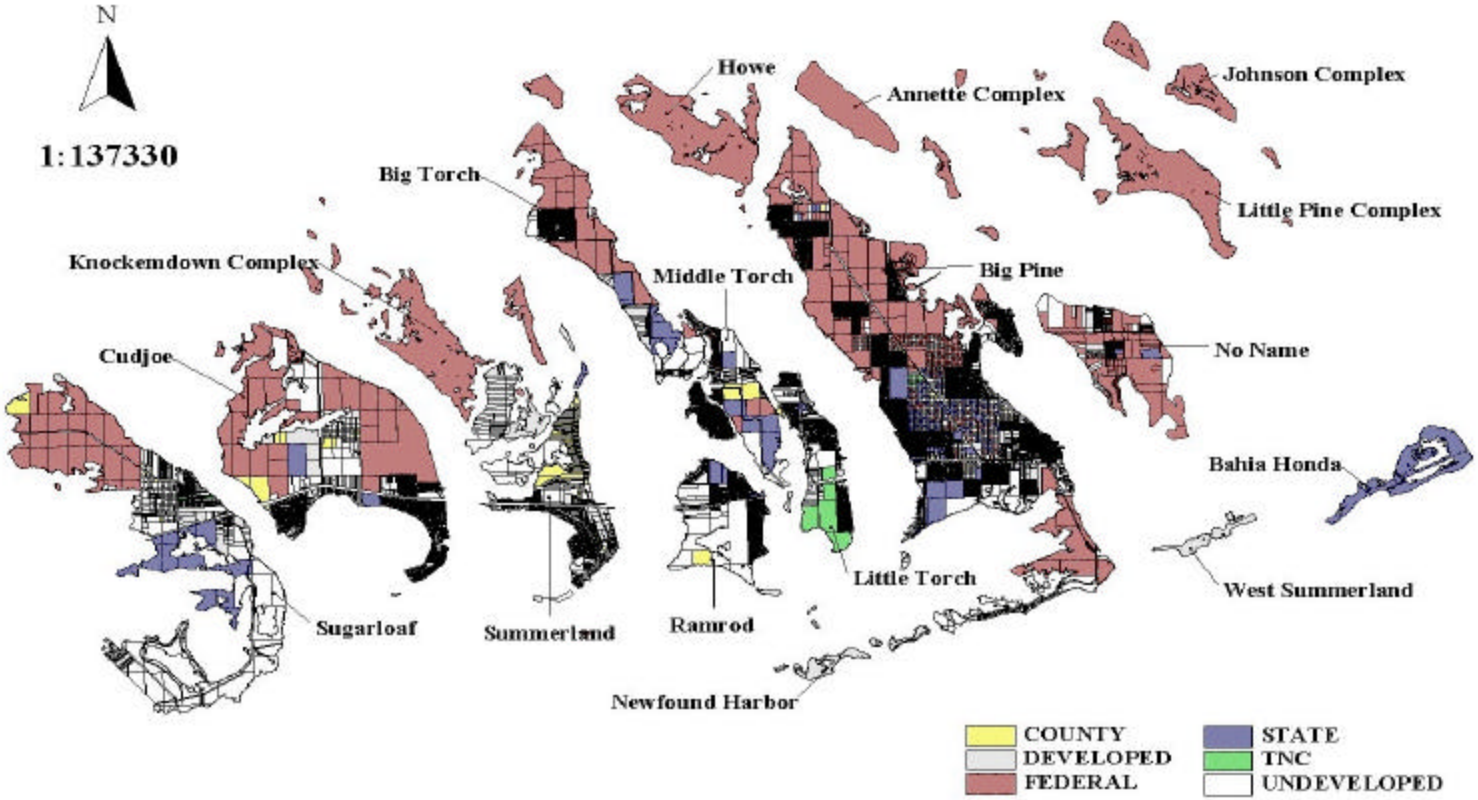


Fig. 1.3. Ownership patterns within the range of the Florida Key deer.

Fig. 1.10. Ownership patterns within the range of the Florida Key deer.

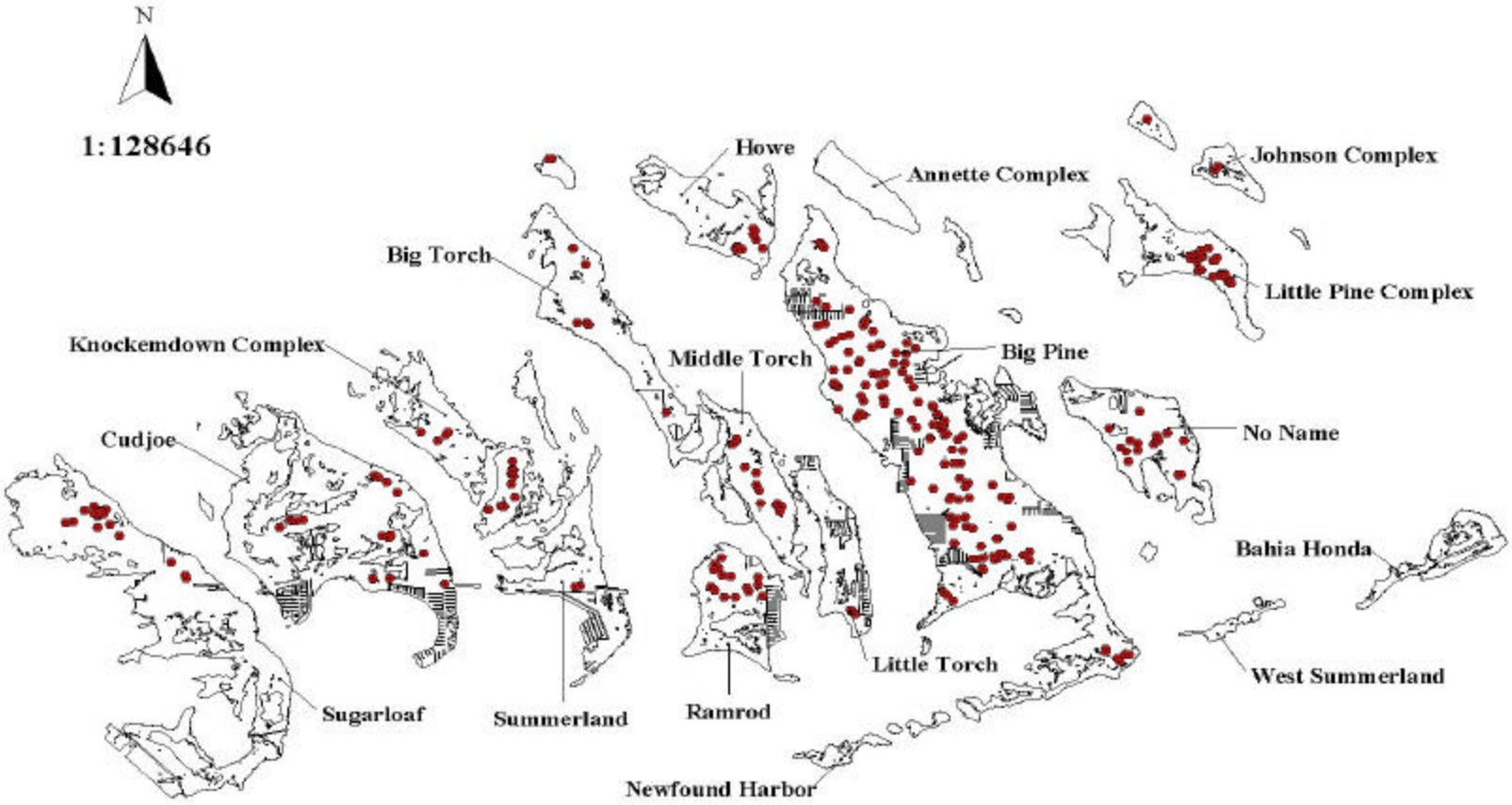


Fig. 1.4. Waterhole distribution (red dots) within the range of the Florida Key deer.

Fig. 1.11. Freshwater sources (red dots) within the range of the Florida Key deer.

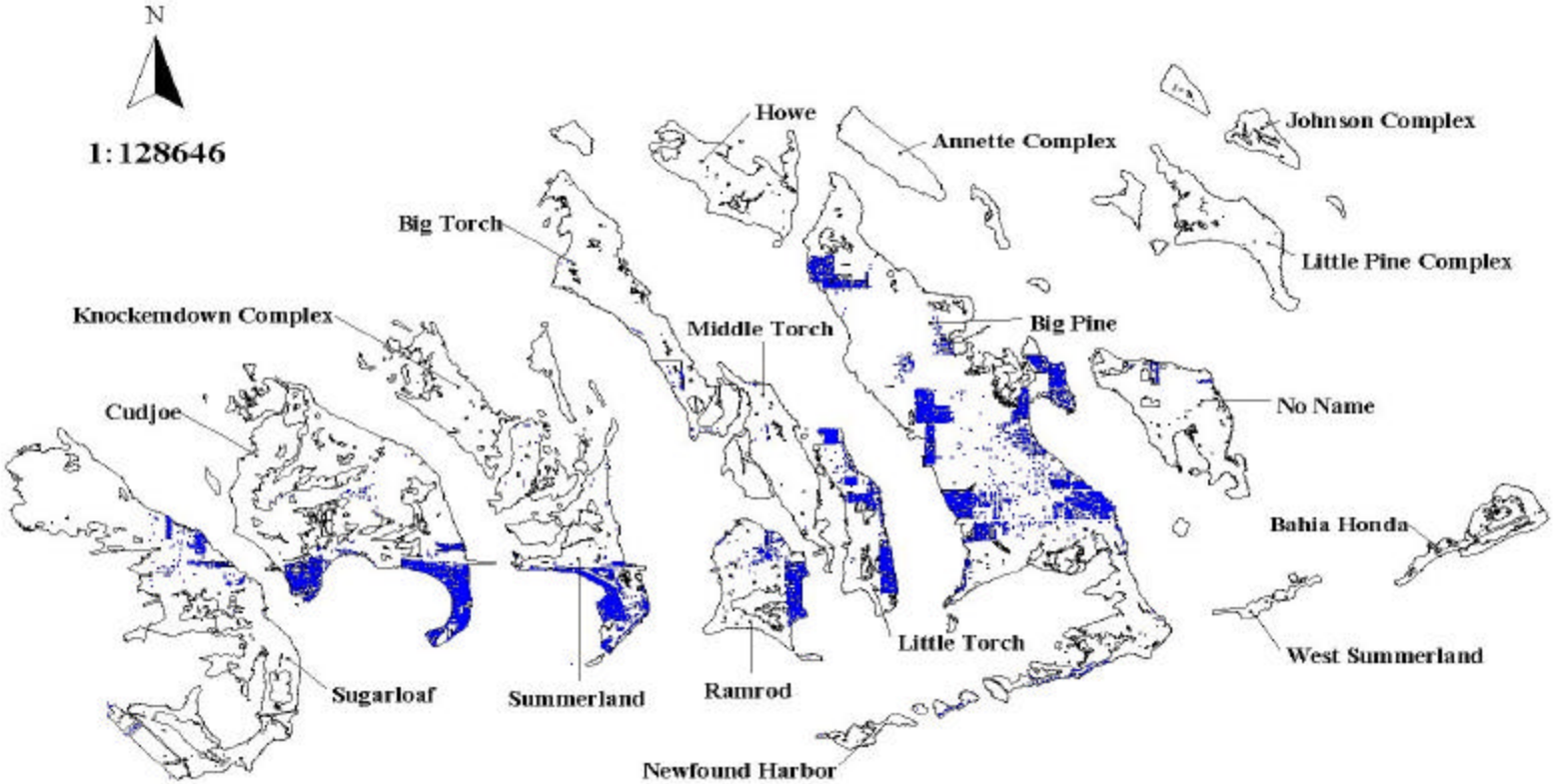


Fig. 1.5. Distribution of development (blue dots) within the range of the Florida Key deer.

Fig. 1.12. Distribution of development (blue dots) within the range of the Florida Key deer.

CHAPTER II

SURVIVAL, MORTALITY, AND LIFE EXPECTANCY

SYNOPSIS

Previous studies report increases in traffic, habitat loss, and human-deer interactions due to urban development threaten the recovery and management of Key deer. To evaluate these threats to the Key deer population, a current assessment of changes in Key deer survival and mortality was necessary. Study objectives were to (1) estimate current survival rates and compare to historic estimates, (2) evaluate the causes of mortality between 1966-00, and (3) determine life expectancy of Key deer from marked animals. Key deer were radio-collared as part of 2 separate field studies (1968-72, 1998-00), in addition to the collection of mortality data and survey estimates (1966-00) by USFWS biologists. Collectively, these data were used to estimate and evaluate trends in survival and mortality for Key deer. Survival data from 314 (females, n = 157; males, n = 157) radio-collared Key deer were analyzed using a known-fate model framework. A suite of *a priori* models were considered based on the biology and current knowledge of Key deer and ranked using Akaike's Information Criterion (AIC_c) model selection. Results suggest sex and geographical location were important factors explaining Key deer survival. Best models had a sex and area interaction, and were all ≤ 1.26 ΔAIC_c from each other, representing approximately 84% of the normalized AIC_c weight of the full suite of models. Annual male survival (0.412-0.842) was lower than female survival (0.695-0.888). Annual deer survival for both sexes was highest for No Name and lowest for south Big Pine. Mortality data (n = 2,151) from deer necropsies found highway mortality accounted for > 50% of deer mortality, half of which occurred on US 1. Other causes of mortality included entanglement, dogs, disease, and drowning. Annual deer mortality in the last 30 years, which is a function of population size, has increased. Marked female deer (n = 35) lived an average of 6.5 years (maximum 19 years) while marked male deer (n = 43) lived an average of 2.9 years (maximum 12 years). Study results suggest highway mortality benefits the Key deer population as an alternative form of predation or hunting, however, a reduction in highway mortality is recommended because of human safety concerns and because road mortalities are an inhumane method of reducing deer numbers.

INTRODUCTION

Increases in urban development, habitat fragmentation, and human-deer interactions threaten the recovery and management of Key deer (Klimstra et al. 1974, Folk 1991). Urban development is of particular concern because previous studies have documented that highway mortality accounts for the majority of the total deer mortality, and is related to urban growth (Hardin 1974, Folk 1991). Since 1970, the human population has increased nearly 10-fold on Big Pine and No Name keys (Chapter I).

USFWS biologists recommend a reduction in Key deer road mortality, particularly on US 1 where over half of all road mortalities occur (Folk 1991). In 1995, due to the inadequate level of service on the US 1 segment servicing Big Pine and No Name keys, a building moratorium was implemented until highway improvements could be addressed (Calvo 1996). Efforts to lift the building moratorium resulted in several proposed development scenarios requiring the evaluation of the potential impact of these scenarios on the Key deer via an HCP (Calvo 1996, Chapter I). Current survival and mortality estimates are required to develop a PVA that is an integral part of this HCP. Current and reliable estimates, however, are not available from other studies.

Key deer were radio-collared as part of 2 separate field studies (1968-72, also referred to as the historic study, and 1998-00, also referred to as the present study). In addition, USFWS biologists have collected deer mortality and survey data since 1966. Collectively, these data addressed several study objectives: (1) estimate current survival rates and compare to historic estimates, (2) evaluate the causes of mortality between 1966-00, and (3) determine life expectancy of Key deer from marked animals

METHODS

Survival

Deer Trapping.—Key deer were radio-collared as part of 2 separate research projects conducted December 1968-June 1972, and January 1998-December 2000 on Big Pine and No Name keys. All data described in this chapter were collected on these 2 islands (Chapter I). Deer were captured using portable drive nets, drop nets, and hand capture (Silvy 1975, Silvy et al. 1975, Lopez et al. 1998) throughout the duration of both studies. Sex, age, location of capture, body weight, radio frequency, and body condition were recorded for each deer prior to release. Key deer classifications used included sex (2 classes – male, female), age (3 classes –

fawn, yearling, adult, Severinghaus 1949), study (2 classes – historic, present), and area (3 classes – NBPK, SBPK, NNK). Captures occurred in 3 distinct areas: north Big Pine Key (NBPK), south Big Pine Key (SBPK), and No Name Key (NNK, Fig. 2.1). Deer that moved from initial capture area were re-classified based on radio-telemetry locations and where they spent the majority of their time. Approximately 85% of radio-collared Key deer, however, did not move from the area of their original capture site (Chapter V). Captured deer were marked in a variety of ways depending on sex and age. Methods used included plastic neck collars (8-cm wide, primarily females of all age-classes), leather antler collars (0.25-cm wide, yearling and adult males only), or elastic expandable neck collars (3-cm wide, primarily male fawns/yearlings). A battery-powered mortality-sensitive radio transmitter (150-152 MHz, 100-110 g for plastic neck collars, 10-20 g for antler transmitters and elastic collars, Advanced Telemetry Systems, Isanti, Minnesota, USA) was attached to collar material. In addition, each animal captured received an ear tattoo, which served as a permanent marker (Silvy 1975).

Radio Telemetry.—Radio-collared deer were monitored for mortalities 6-7 times per week at random intervals (24-hour period was divided into 6 equal 4-hour segments; 1 (4-hour) segment was randomly selected and during that time all deer were located, Silvy 1975). Any detected mortality was immediately located, and the animal necropsied to determine cause of mortality. For cases in which radios failed or disappeared, animals were censored from the data set after its last known encounter (Pollock et al. 1989).

Data Analysis.—Survival data were analyzed using a known-fate model framework in Program MARK (White and Burnham 1998). Use of a known-fate model is the appropriate method to analyze survival data where animals are regularly monitored using telemetry and were alive, dead, or censored from the data set. Field telemetry data were converted into an encounter history file for input into program MARK using SAS (SAS 1999). Individual encounter histories were created for each deer with each animal being placed into 1 of 36 classification groups based on age (3 classes), sex (2 classes), area (3 classes) and study (2 classes). Deer entered the next age class on 1 April, with animals spending a maximum of 1 year as fawns, 1 year as yearlings, and then staying in the adult age class until death (Silvy 1975). While field survival monitoring was done on a daily basis, each 7 days of monitoring data were collapsed into a weekly survival for each animal. Beginning with the week it was radio-collared, each deer had a weekly survival history during which it either lived, died, was censored, or the study ended.

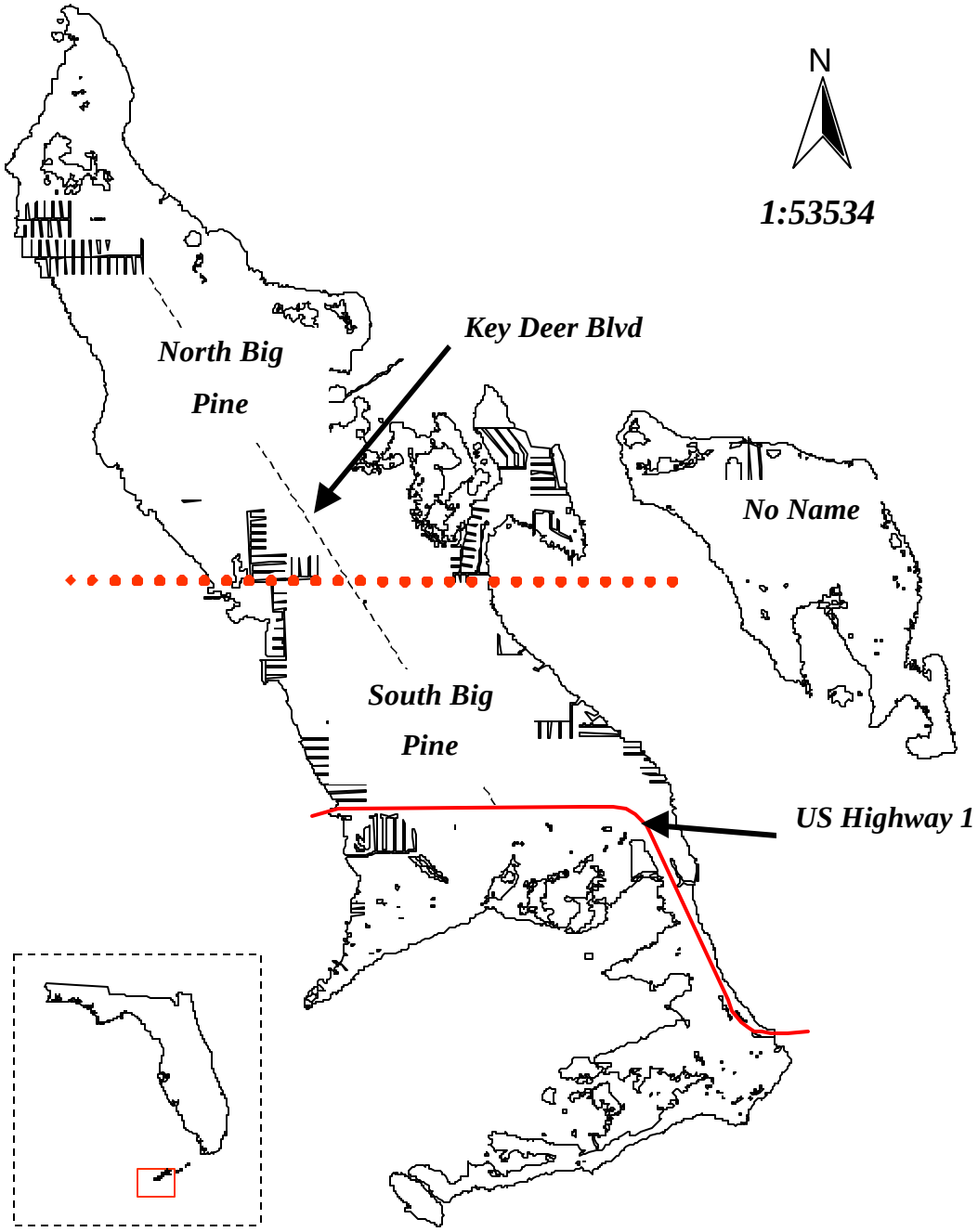


Fig. 2.1. Study areas within the Key deer range, Big Pine (north and south) and No Name keys.

A suite of *a priori* models were considered for the Program MARK analysis. This paradigm for model creation was assessed by Burnham and Anderson (1998) and shown to reduce the possibility of spurious results, as might occur with model over-fitting when each potential model is inspected for fit before the next one is analyzed. Sixteen *a priori* models were developed based on the biology and current knowledge of Key deer. Program MARK uses Akaike's Information Criterion (AIC_c) model selection to rank each potential model (Burnham and Anderson 1998). AIC_c is a model selection procedure in which the considered suite of models are evaluated relative to an unknown and unconsidered model representing truth. Each model's AIC_c value was calculated as

$$\mathrm{AIC_c} = -2(\mathrm{loglikelihood}) + 2K + \frac{2K(K+1)}{n-K-1}.$$

where K is the number of regression parameters. This comparison allows each model to have a relative value (AIC_c value) or ranking among the suite of models considered. The relative difference between models is best quantified by giving each model a ΔAIC_c value, that is calculated by subtracting the AIC_c of a given model with the minimum AIC_c model. This new ΔAIC_c value provides a good tool for relative model comparison, with the "best" model among those considered having a ΔAIC_c value of 0, and other models follow in ranking with increasing ΔAIC_c values (Leberton et al. 1992, Burnham and Anderson 1998). Each model had a series of weekly survival estimates based on the variables considered in that model. However, by limiting inference to just 1 model and its estimates, none of the uncertainty in the model selection process was incorporated in the estimates. Uncertainty was incorporated by model-averaging final survival estimates. For each model (*m*), a normalized AIC_c weight (w_m) was calculated as:

$$\hat{w}_m = \frac{e^{-\frac{1}{2}\Delta \mathrm{AICc}_m}}{\sum_{r=1}^{R} e^{-\frac{1}{2}\Delta \mathrm{AICc}_r}}.$$

This AIC_c weight is used to weigh the proportion of each model's estimates relative to all evaluated models (*R*) in their contribution to the overall model-averaged survival estimates. Conclusions were based on model-averaged estimates and SEs, thereby incorporating model selection uncertainty in the analysis. Such uncertainty is recommended for use in PVA's (White 2000). Annual survival estimates were obtained from weekly estimates (n = 52) using

$$\bar{\hat{S}}_{yearly} = (\bar{\hat{S}}_{weekly})^n$$

and annual survival SE estimates were calculated from model-averaged weekly SE estimates using

$$\hat{SE}(\bar{\hat{S}}_{weekly}) = \sqrt{V\hat{a}r(\bar{\hat{S}}_{weekly})}$$

and

$$\hat{SE}(\bar{\hat{S}}_{yearly}) = \sqrt{e^{2\ln(n)+2(n-1)\ln(S_{weekly})}\,\hat{SE}(\bar{\hat{S}}_{weekly})^2} \quad .$$

Mortality

Necropsies.—NKDR staff have recorded Key deer mortality since 1966. Direct sightings, citizen reports, or observation of turkey vultures located most dead animals, and animals collected were held frozen prior to necropsy examination. Carcass quality or ability to determine cause of death ranged from good to marginal. Age, sex, body weight, and cause of death were recorded for each animal using procedures described by Nettles (1981), and all mortality locations were inputted into a GIS using ArcView (Version 3.2) and Microsoft Access (Version 97).

Population Trends.—Spotlight counts were conducted monthly by USFWS biologists along a standard route for Big Pine (56-km) and No Name keys (3-km) at 2000-2100 hours (Chapter IV). These surveys provided the refuge with an index of population size. Number of deer observed along the route were recorded in addition to sex and age (fawn, yearling, and adult) estimates. The average number of deer seen annually was calculated, and compared to annual deer mortality.

Data Analysis.—Trends in deer mortality were examined by sex, age, island, area, year/period, data source, and mortality agent. Spatial assignments by area were determined using ArcView. Data were summarized in tables or figures, and differences in deer mortality by category were tested when appropriate, using a Chi-square goodness-of-fit test (Ott 1993).

Life Expectancy

Life expectancy, defined as the mean age of death for members of a cohort, can validate survival estimates using population matrix models (Caughley 1977, Caswell 2000). Following termination of the historic study in 1972, collars were not removed from animals, offering a unique opportunity to calculate life expectancy for an unhunted, long-lived wild deer population. NKDR refuge staff collected and recorded mortalities of marked deer since the end of the historic study. In this study, a review of the mortality database identified marked animals captured as fawns or yearlings with a known fate, and these data were used to determine life expectancy estimates and maximum ages.

RESULTS

Survival

Results from the model selection procedure suggest sex and area were important factors explaining Key deer survival (Table 2.1). Models that included some permutation of sex and area effects represented the top 7 of 16 models (Tables 2.2-2.3). Three of the top 4 models had a sex and area interaction, and some form of separate fawn survival, suggesting that age might differ for fawns, with adult and yearling survival being more similar. These top 4 models were all ≤ 1.26 ΔAIC_c from each other and represented approximately 84% of the normalized AIC_c weight of the full suite of models. By far the greatest influence on survival estimates came from these 4 models. Both Models 3 (age) and 4 (study) were ranked last in the considered group, and had no contribution to the model-averaged estimates due to their normalized AIC_c weights of 0.000 (Tables 2.2-2.3).

Model-averaged annual survival estimates by sex and area ranged from 0.695-0.888 (SE 0.033-0.132) for females and 0.412-0.842 (SE 0.060-0.158) for males (Table 2.4). In general, annual survival for males was lower than female survival. Furthermore, annual survival for both sexes was highest for NNK deer and lowest for SBPK deer (Table 2.4, Figs. 2.2-2.3). Model-averaged annual survival estimates were calculated by sex and age to be used in PVA model, and ranged from 0.615-0.842 (SE 0.030-0.149) for females and 0.569-0.597 (SE 0.054-0.110) for males (Table 2.5).

Mortality

Highway mortality accounted for the majority (> 50%) of deer mortality (X^2 = 6,489.74, 6 df, P < 0.001, Tables 2.6-2.7, Figs. 2.4-2.5). Other Key deer mortality agents included entanglement, dogs, disease, and drowning (Table 2.6).

Sex Effect.—Since 1966, annual deer mortality has been higher for males than females. Overall, recorded male mortality was over 1.5 times that of female mortality (X^2 = 97.62, 1 df, P < 0.001, Table 2.6, Fig. 2.4). Differential survival estimates observed between sexes from telemetry data supports differences in mortality between sexes from necropsy data. Furthermore, data also indicates seasonal differences in deer mortality with male mortality increasing during the breeding season (Fig. 2.6).

Area Effect.—Key deer had a greater susceptibility to mortality, particularly highway mortality, as deer moved closer to the US 1 corridor (SBPK). Highest deer mortality observed for both sexes was in SBPK, followed by NBPK and NNK (Fig. 2.7). Of the 1,596 roadkill Key

deer, approximately 51.6% occurred on US 1, 18.4% on Key Deer Boulevard, and remaining areas accounted for 29.9% (Table 2.7).

Population Trends.—No difference in survival or mortality causes (%) between studies was found (Tables 2.3 and 2.6). In reviewing mortality data from telemetry sources only, approximately 50% of the total deer mortality was caused by road mortality (Table 2.6). Despite similar trends in survival and mortality estimates between studies, however, annual deer deaths have increased in the past 30 years. Data suggests annual deer mortality is a function of deer density or population size; a correlation (r^2 = 0.56) between annual deer mortality and annual monthly road count data (1976-00, n = 266 road counts) exists (Fig. 2.8).

Survey data illustrates the population sex ratio and distribution of Key deer males and females on Big Pine Key is skewed. For example, of 6,575 Key deer observed in recent road counts (1998-00, n = 379 road counts) for Big Pine Key, approximately 69.6% and 30.5% were females and males, respectively. In comparing the distribution of sexes by area on Big Pine Key, the proportion of deer observed in NBPK was 74.7% females and 25.3% males, whereas the proportion of deer observed in SBPK was 55.6% females and 44.4% males. A greater proportion of Key deer males reside in the southern portion of Big Pine Key where deer face the greatest threats (traffic, fences, Chapter IV).

Biases.—Highway mortality based on radio telemetry data accounted for approximately 50% of the total deer mortality. However, mortality data collected by USFWS biologists reports a slightly higher estimate of 74% (Table 2.6). Higher roadkill estimates (USFWS mortality database) are due to observer bias in detecting road mortality in comparison to other forms of deer mortality. Use of road mortality data should be used with caution as a result of this bias.

Life Expectancy

Life expectancy for 78 known-fate marked Key deer (females, n = 35; males, n = 43) averaged about 6.5 years (maximum 19 years) for females while the average male lived about 2.9 years (maximum 12 years). The combined average was approximately 4.5 years.

Table 2.1. Demographics of 314 radio-collared Florida Key deer on Big Pine and No Name keys, 1968-72 and 1998-00.

Study		
Sex	Age	*n*
Historic (Telemetry 1968-72)		
Female	Adult	39
	Yearling	8
	Fawn	21
	Total	68
Male	Adult	19
	Yearling	5
	Fawn	40
	Total	64
Total		132
Present (Telemetry 1998-00)		
Female	Adult	57
	Yearling	22
	Fawn	10
	Total	89
Male	Adult	50
	Yearling	33
	Fawn	10
	Total	93
Total		182
Grand Total		314

Table 2.2. Suite of 16 *a priori* models considered in weekly survival estimates from radio-collared Florida Key deer (*n* = 314) on Big Pine and No Name keys, 1968-72 and 1998-00.

Model number	Model structure
1	*S*(sex)
2	*S*(area)
3	*S*(age)
4	*S*(study)
5	*S*(age*sex + no sex effects in fawns)
6	*S*(age*sex)
7	*S*(sex*area*study)
8	*S*(age*sex*study)
9	*S*(sex*area*age)
10	*S*(sex*area + all fawns having own *S* + all NNK deer having own *S*, including fawns)
11	*S*(sex*area + all fawns having own *S* + all NNK deer having own *S*, excluding fawns)
12	*S*(area + sex)
13	*S*(sex*area + all fawns having own *S*)
14	*S*(sex*area + all fawns having own *S*, varying by sex)
15	*S*(sex*area + all NNK deer having own *S*)
16	*S*(sex*area)

Table 2.3. AIC_c ranking of 16 *a priori* models used to estimate model-averaged weekly survival rates for radio-collared Florida Key deer (*n* = 314) on Big Pine and No Name keys, 1968-72 and 1998-00.

Model number	Model structure	*K*	AIC_c	ΔAIC_c	w_m
10	*S*(sex*area + all fawns having own *S* + all NNK deer having own *S*, including fawns)	6	972.68	0.00	0.2536
11	*S*(sex*area + all fawns having own *S* + all NNK deer having own *S*, excluding fawns)	6	972.75	0.07	0.2449
12	*S*(area + sex)	4	973.06	0.38	0.2101
13	*S*(sex*area + all fawns having own *S*)	7	973.94	1.26	0.1351
14	*S*(sex*area + all fawns having own *S*, varying by sex)	8	975.46	2.78	0.0632
15	*S*(sex*area + all NNK deer having own *S*)	5	975.74	3.06	0.0550
16	*S*(sex*area)	6	976.94	4.25	0.0302
1	*S*(sex)	2	980.69	8.01	0.0046
5	*S*(age*sex + no sex effects in fawns)	5	982.79	10.10	0.0016
6	*S*(age*sex)	6	984.31	11.62	0.0008
7	*S*(sex*area*study)	12	987.66	14.97	0.0001
8	*S*(age*sex*study)	12	988.10	15.42	0.0001
2	*S*(area)	3	990.50	17.82	0.0000
9	*S*(sex*area*age)	18	991.16	18.48	0.0000
4	*S*(study)	2	998.93	26.25	0.0000

Table 2.4. Weekly and annual survival and variance estimates by sex, age, and area (model 10) for radio-collared Florida Key deer (*n* = 314) on Big Pine and No Name keys, 1968-72 and 1998-00.

		Weekly				Annual			
Sex				95% LCI	95% UCI			95% LCI	95% UCI
Age	Area	*S*	SE	(logit)	(logit)	*S*	SE	(logit)	(logit)
Female									
Fawn	NNK	0.994	0.003	0.982	0.998	0.746	0.132	0.384	0.914
Fawn	NBPK	0.994	0.003	0.985	0.998	0.726	0.109	0.449	0.880
Fawn	SBPK	0.993	0.003	0.986	0.997	0.695	0.091	0.478	0.836
Yearling	NNK	0.998	0.001	0.994	0.999	0.888	0.056	0.715	0.959
Yearling	NBPK	0.997	0.001	0.995	0.998	0.848	0.033	0.770	0.902
Yearling	SBPK	0.993	0.002	0.987	0.997	0.710	0.082	0.515	0.839
Adult	NNK	0.998	0.001	0.994	0.999	0.888	0.056	0.715	0.959
Adult	NBPK	0.997	0.001	0.995	0.998	0.848	0.033	0.770	0.901
Adult	SBPK	0.993	0.002	0.987	0.997	0.710	0.082	0.515	0.839
Male									
Fawn	NNK	0.995	0.003	0.986	0.998	0.774	0.109	0.474	0.916
Fawn	NBPK	0.992	0.003	0.985	0.996	0.668	0.091	0.458	0.812
Fawn	SBPK	0.990	0.005	0.973	0.996	0.599	0.158	0.246	0.830
Yearling	NNK	0.997	0.002	0.992	0.999	0.842	0.069	0.645	0.934
Yearling	NBPK	0.990	0.002	0.985	0.993	0.583	0.060	0.457	0.690
Yearling	SBPK	0.983	0.005	0.971	0.990	0.412	0.099	0.222	0.594
Adult	NNK	0.997	0.002	0.992	0.999	0.842	0.069	0.645	0.934
Adult	NBPK	0.990	0.002	0.985	0.993	0.583	0.060	0.458	0.690
Adult	SBPK	0.983	0.005	0.971	0.990	0.412	0.099	0.222	0.594

Table 2.5. Weekly and annual survival and variance estimates by sex and age (models 5-6) for radio-collared Florida Key deer (*n* = 314) on Big Pine and No Name keys, 1968-72 and 1998-00.

		Weekly				Annual			
				95% LCI	95% UCI			95% LCI	95% UCI
Sex	Age	*S*	SE	(logit)	(logit)	*S*	SE	(logit)	(logit)
Female	Fawn	0.991	0.005	0.975	0.997	0.615	0.149	0.275	0.834
Female	Yearling	0.996	0.002	0.991	0.998	0.824	0.071	0.628	0.923
Female	Adult	0.997	0.001	0.995	0.998	0.842	0.030	0.772	0.892
Male	Fawn	0.994	0.003	0.985	0.998	0.743	0.110	0.454	0.895
Male	Yearling	0.989	0.003	0.982	0.994	0.569	0.089	0.379	0.721
Male	Adult	0.990	0.002	0.986	0.993	0.597	0.054	0.483	0.695
All	Fawn	0.993	0.002	0.986	0.996	0.692	0.090	0.479	0.832
Female	Yearling	0.996	0.002	0.991	0.998	0.824	0.071	0.628	0.923
Female	Adult	0.997	0.001	0.995	0.998	0.842	0.030	0.772	0.892
Male	Yearling	0.989	0.003	0.982	0.994	0.569	0.089	0.379	0.721
Male	Adult	0.990	0.002	0.986	0.993	0.597	0.054	0.483	0.695

Table 2.6. Mortality agent by sex and data source for Florida Key deer on Big Pine and No Name keys, 1966-00.

Data source Cause	Female	Male	Unknown	Total	%
USFWS (1966-00)					
Entanglement	11	13	0	24	1.12
Dog	19	23	1	43	2.00
Disease	11	36	0	47	2.19
Drowning	14	38	8	60	2.79
Unknown	22	46	6	74	3.44
Other	117	162	28	307	14.27
Roadkill	594	988	14	1,596	74.20
Total	788	1,306	57	2,151	100.00
Historic (1968-72)					
Entanglement	0	0	—	0	0.00
Dog	0	1	—	1	1.92
Disease	0	0	—	0	0.00
Drowning	2	3	—	5	9.62
Unknown	4	9	—	13	25.00
Other	2	5	—	7	13.46
Roadkill	8	18	—	26	50.00
Total	16	36	—	52	100.00
Present (1998-00)					
Entanglement	1	2	—	3	7.89
Dog	1	0	—	1	2.63
Disease	1	1	—	2	5.26
Drowning	0	1	—	1	2.63
Unknown	3	5	—	8	21.05
Other	3	1	—	4	10.53

Table 2.6. Continued.

Data source Cause	Female	Male	Unknown	Total	%
Roadkill	8	11	—	19	50.00
Total	17	21	—	38	100.00

Table 2.7. Highway mortality by sex, age, and area for Florida Key deer (*n* = 1,596) on Big Pine and No Name keys, 1966-00.

		Big Pine				
Sex	Age	US 1	Key Deer Blvd	Other	No Name	Total
Female	Adult	143	70	91	19	323
	Yearling	59	29	25	5	118
	Fawn	25	31	47	11	114
	Unknown	16	8	9	6	39
	Total	243	138	172	41	594
	% by Area	40.9	23.2	29.0	6.9	100.0
Male	Adult	311	67	87	35	500
	Yearling	157	35	44	18	254
	Fawn	85	46	51	12	194
	Unknown	22	5	11	2	40
	Total	575	153	193	67	988
	% by Area	58.2	15.5	19.5	6.8	100.0
Unknown	Adult	2	0	0	0	2
	Yearling	0	0	0	0	0
	Fawn	2	2	4	1	9
	Unknown	2	1	0	0	3
	Total	6	3	4	1	14
	% by Area	42.9	21.4	28.6	7.1	100.0
Total		824	294	369	109	1,596
	% by Area	51.6	18.4	23.1	6.8	100.0

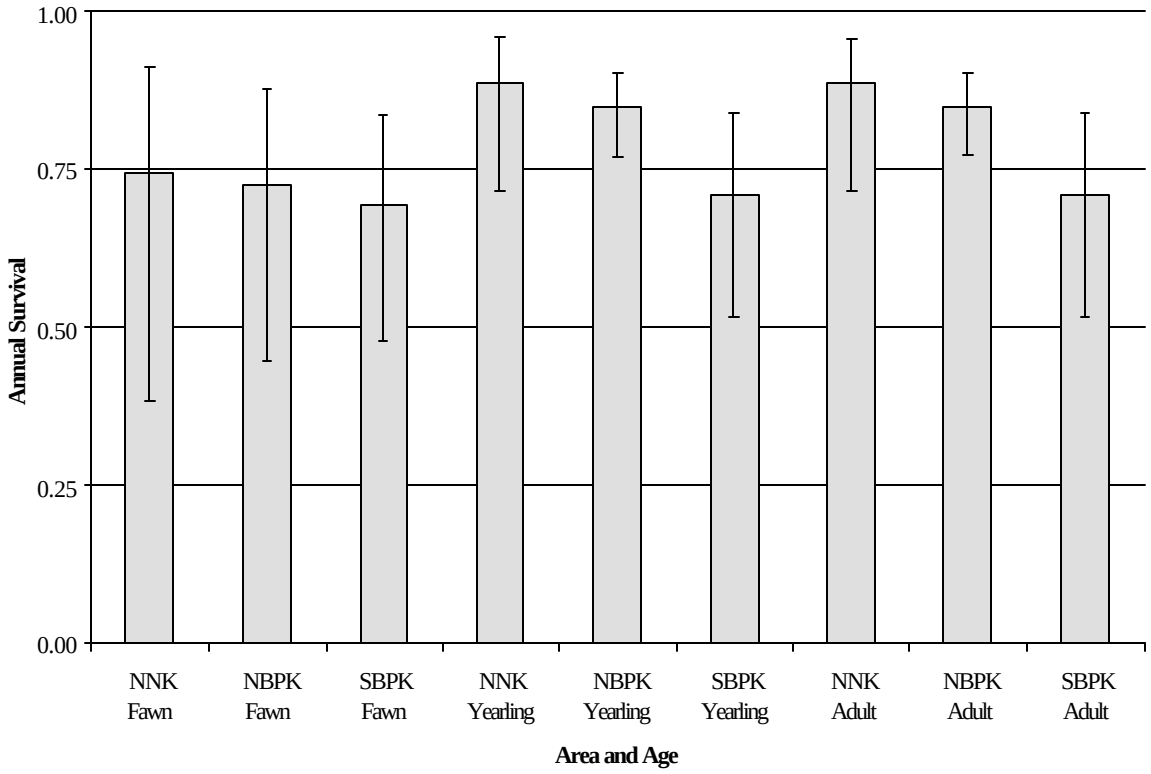


Fig. 2.2. Annual female Key deer (*n* = 157) survival and 95% error bars by age-class and area (NNK = No Name, NBPK = North Big Pine, and SBPK = South Big Pine), 1968-72 and 1998-00.

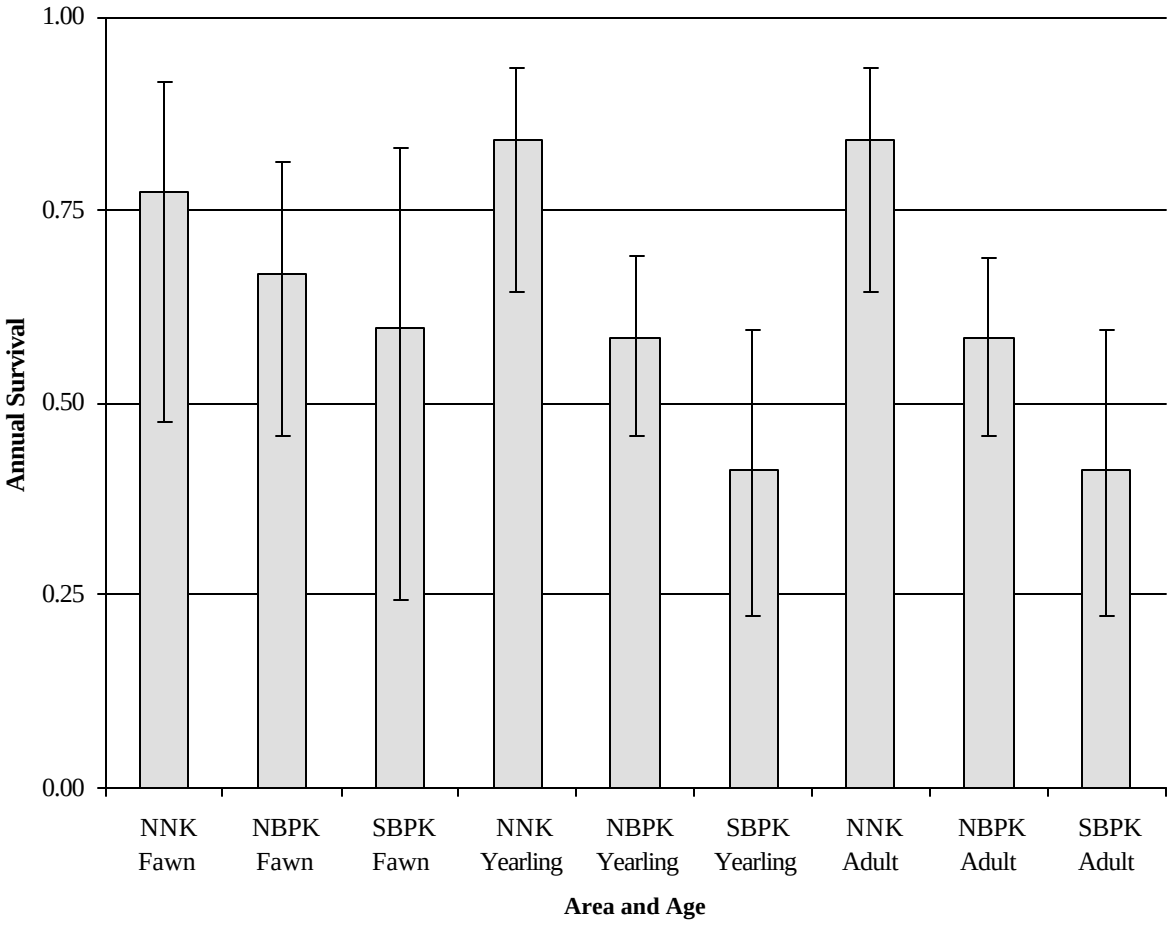


Fig. 2.3. Annual male Key deer (*n* = 157) survival and 95% error bars by age-class and area (NNK = No Name, NBPK = North Big Pine, and SBPK = South Big Pine), 1968-72 and 1998-00.

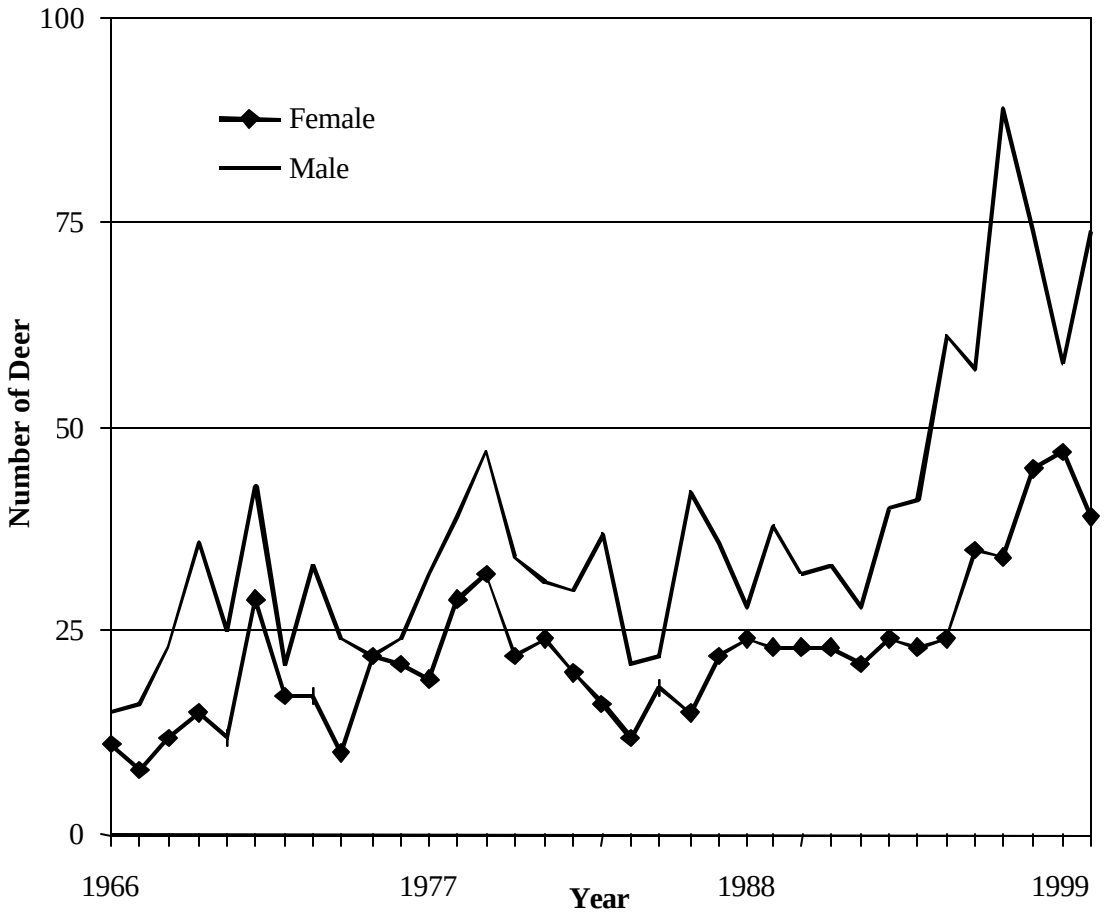


Fig. 2.4. Annual Key deer mortality (*n* = 2,151) by sex on Big Pine and No Name keys, 1966-00.

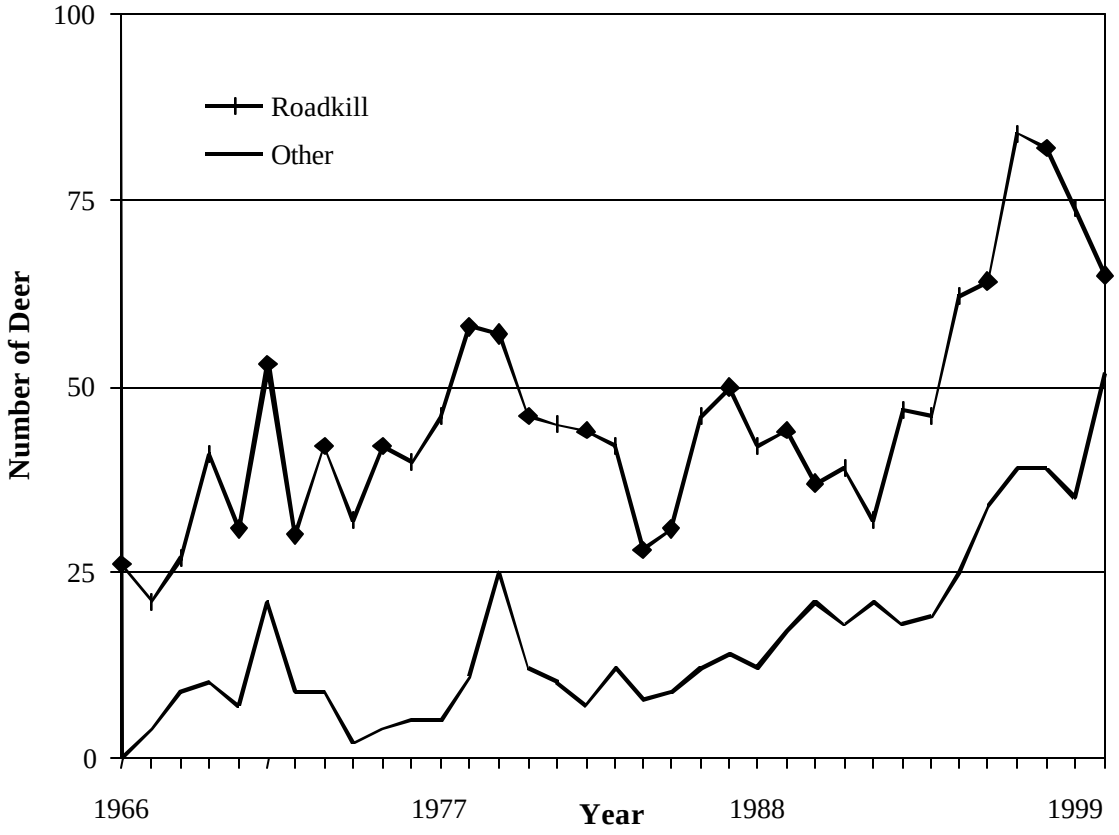


Fig. 2.5. Annual Key deer mortality (*n* = 2,151) by mortality agent on Big Pine and No Name keys, 1966-00.

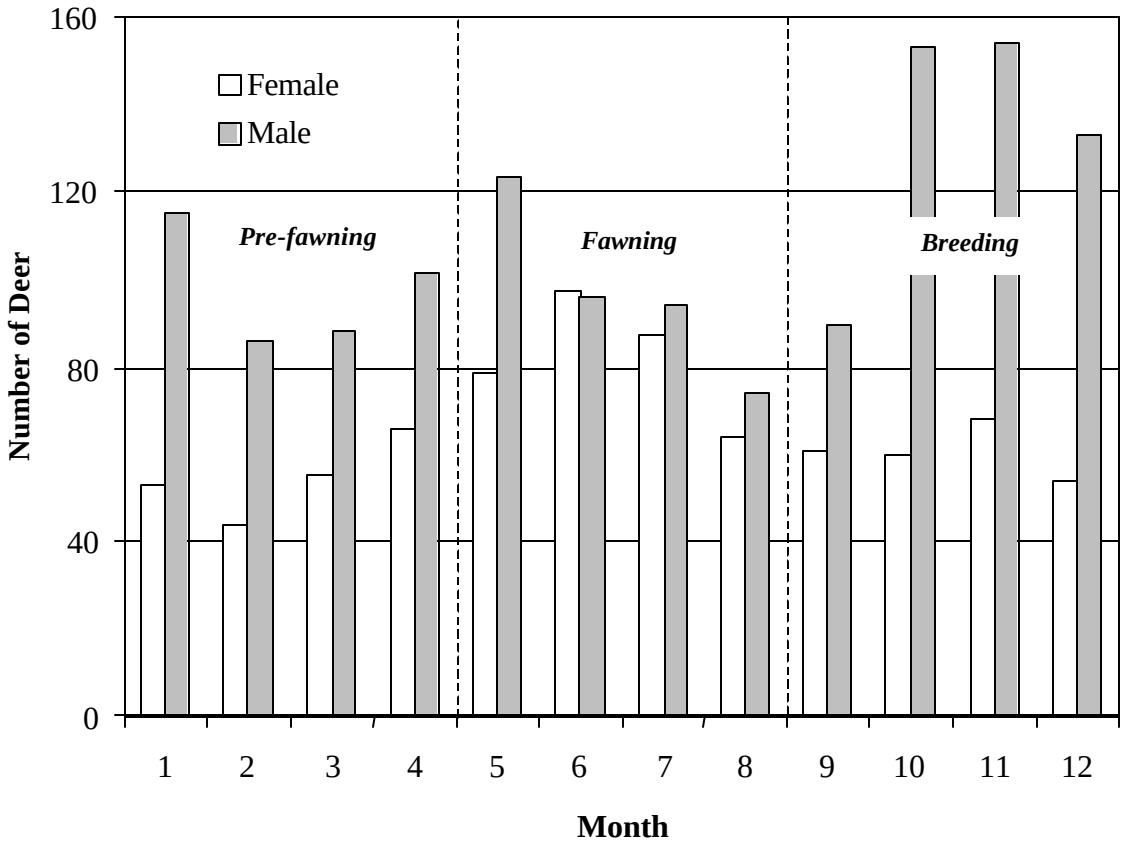


Fig. 2.6. Key deer mortality (*n* = 2,151) by sex, month, and reproductive season on Big Pine and No Name keys, 1966-00.

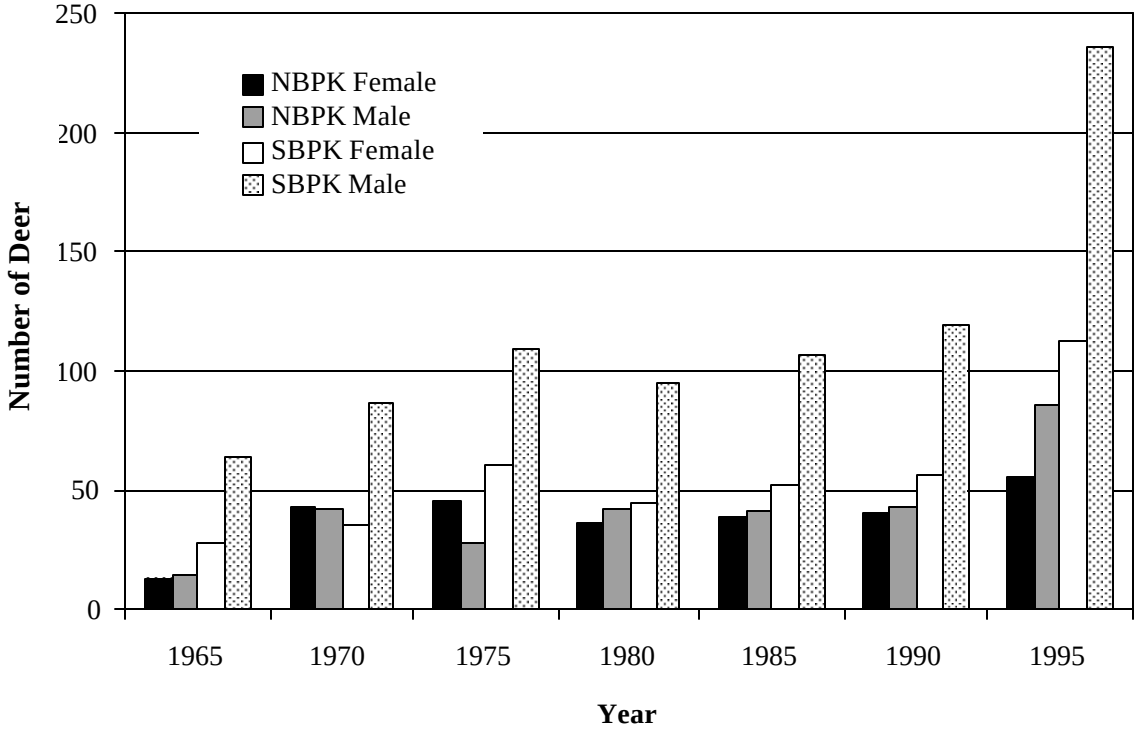


Fig. 2.7. Key deer mortality by sex and area in 5-year increments on Big Pine Key, 1966-00.

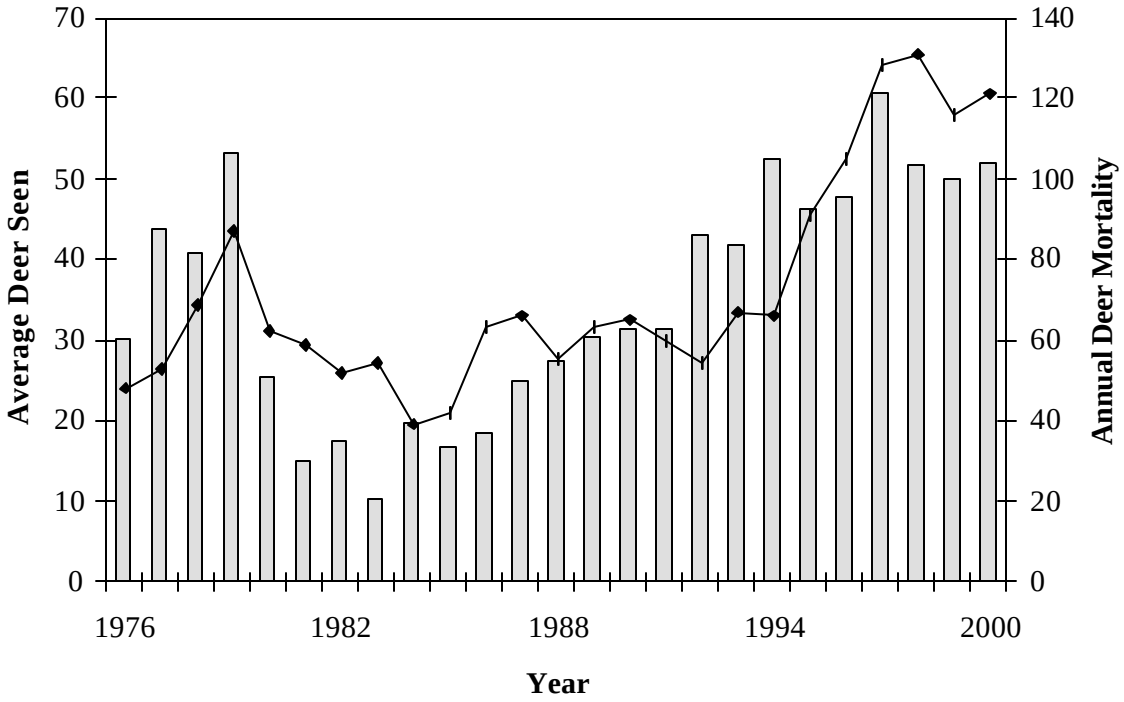


Fig. 2.8. Average deer seen (line) on USFWS monthly road counts and annual deer mortality (bars) on Big Pine and No Name keys, 1976-00.

DISCUSSION

This study elucidated several interesting survival and mortality patterns that are important in understanding the population dynamics of Key deer. It has been assumed that urban development and other anthropogenic factors threaten the viability of the Key deer population (Folk 1991). For example, other studies (Hardin 1974, Klimstra et al. 1974, Folk 1991) report highway mortality accounts for the majority of observed Key deer mortality. Survival and mortality estimates in this study support these findings. The impact of highway mortality on the Key deer population, however, is relatively recent. Historically, illegal hunting or poaching reduced deer numbers to an estimated 50 animals in the 1930's (Dickson 1955, Folk 1991). Protection of Key deer through law enforcement efforts resulted in a population increase to a current estimate of 600-700 deer (Chapter IV). Despite increases in highway mortality and urban development, the Key deer population has increased nearly 240% in the last 30 years (Chapter IV).

Sex Effect

Male Key deer face a greater mortality risk than females. Other studies (Loison et al. 1999, Caswell 2000, Demarais et al. 2000) have documented differential survival between sexes for other species of ungulates (white-tailed deer, roe deer, *Capreolus capreolus*; bighorn sheep, *Ovis canadensis*; and isard, *Rupicapra pyrenaica*). Loison et al. (1999) and Demarais et al. (2000) hypothesized that differences in social behavior between sexes, particularly reproductive behavior (e.g., greater male seasonal movements, male-male aggression), resulted in differential survival for males and females. For example, in this study Key deer male ranges and average daily movements were nearly double that of female deer (Chapter V). Greater movements observed for males might explained by an increased mortality risk, particularly due to road mortality. Lower male survival observed in this study, however, does not appear to have impacted population growth as survey data (1968-00) indicates the deer population on Big Pine and No Name keys has grown 1-10% annually (Chapter IV). Similar results (1-5% annual population rates) were observed using age-structured models that incorporated survival and fecundity estimates (Chapter VII).

Studies (Klimstra et al. 1974, Hardin 1974, Folk and Klimstra 1991a) report Key deer fetal sex ratios are male-biased (57-74% males). Poor nutrition of does is often cited as the reason for male bias in fetal sex ratios from the theoretical 1:1 ratio (Verme 1983, Caley and Nudds 1987, Folk and Klimstra 1991a). Despite the male-biased fetal sex ratio observed in the

Key deer population, the overall population sex ratio for Big Pine is female-biased (69.5% females, 30.5% males), and contrary to what would be expected (Chapter IV). The female-bias sex ratio observed in Big Pine might be explained by (1) differential survival between sexes, and (2) differential survival between areas. First, higher female survival would eventually favor a female-biased population sex ratio. Second, 74.7% females were observed in NBPK as compared to 55.6% females in SBPK; fewer females and lower survival in SBPK would result in the mortality of more males. For these reasons, it is proposed that differential survival between sexes and the distribution of Key deer sex on the island results in a female-bias population sex ratio.

Age Effect

Model results suggest that survival, though not significant, might differ between fawns and other age classes (Tables 2.2-2.3). Other studies (Hardin 1974, Loison et al. 1999) report lower fawn survival compared to other age-classes (yearlings, adults). Fawn survival in this study is likely overestimated due to the difficulty in capturing fawns < 4 months of age (approximately 15% of total radio-collared fawns were < 4 months of age). Other studies (Hardin 1974, Loison et al. 1999, Demarais et al. 2000) document the majority of fawn mortality occurs in the first 6 months. Corrective measures include future research on fawn survival (particularly for fawns < 4 months) using radio telemetry to improve survival estimates.

Area Effect

Key deer survival was found to vary depending on the area occupied by radio-collared animals (Tables 2.2-2.3). In general, deer survival increased as deer moved away from US 1 (SBPK, lowest survival; NNK, highest survival). US 1 bisects the southern portion of Big Pine Key; thus, higher speeds and greater traffic levels on US 1 collectively increase Key deer susceptibility to road mortality. This relationship appears to impact both sexes similarly (Fig. 2.7). Dias (1996) and Wilson (2001) suggested areas occupied by a species could be divided into sources and sinks, depending on whether local reproduction is sufficient to balance mortality. Source populations are those where reproduction exceeds mortality, surplus individuals dispersing to sink populations where mortality exceeds local reproduction. Sink populations would not be viable in the absence of immigration (Dias 1996). In applying this concept to the Key deer population, NBPK can be described as a source (high quality habitat, greater and high deer densities) with SBPK being a sink (low quality habitat and low deer densities). Study results suggest that future development on Big Pine Key should be directed

into areas of high road mortality risk (sinks) rather than areas where road mortality is presently low (sources).

Population Trends

Based on telemetry data, highway mortality proportions has not changed between the present and historic studies. Other mortality agents, however, appear to have increased. Deer entanglement in fences (+7.89%) has increased most likely due to increased urban development. There has also been an increase in disease incidence (+5.26%) in the last 30 years. Schulte et al. (1976) noted relatively low incidence or absence of diseases in the Key deer population in the early 1970's. Since 1986, monitoring by the Southeastern Cooperative Wildlife Disease Study has documented disease increases in the Key deer population, including intestinal parasites (e.g., large stomach worm, *Haemonchus contortus*) that are population limiting (Nettles et al. 2001). Nettles et al. (2001) reported increases in the incidence of diseases are a result of high deer populations at or above carrying capacity.

There was a decrease in the incidence of drowning (-6.98%) from the historic to the present study. This decrease can be explained by the combined influence of 2 factors. First, mosquito ditches (approximately 30 cm wide, 1-2 m deep, length varied) were originally trenched in the 1950's to connect freshwater holes to salt water channels (Folk 1991). This practice was used to prevent mosquito breeding by the introduction of salt water into freshwater holes that served as breeding sites (Hardin 1974, Folk 1991). Hardin (1974) noted the susceptibility of young fawns to drowning in these ditches when attempting to cross. The silting and filling of many mosquito ditches in the last 30 years might explain the observed decrease in the incidence of drowning. Second, fewer fawns < 4 months of age were radio-collared in the present study likely underestimating the frequency of fawn drownings. Thus, the combination of these factors has resulted in lower documented drownings.

Data Biases

Previous studies reported that highway mortality accounted for 60-75% of total deer mortality (Hardin 1974, Hardin et al. 1984, Klimstra et al. 1974, Folk and Klimstra 1991b). It is important to note, however, the contribution of road mortality to overall deer mortality is likely overestimated due to high visibility of roadkill carcasses and public awareness of the problem of Key deer road mortality. In contrast, deer that die of natural causes have a lower probability of being found. Telemetry data from both the historic and present studies found highway mortality

was 50% of the total deer mortality, illustrating how the mortality database overestimated road mortality incidence due to differences in detectability.

Life Expectancy

Female Key deer lived an average of 6.5 years (maximum 19 years) as compared to 3.0 years (maximum 12 years) for males. Life expectancy estimates for other white-tailed deer populations varied due to human-induced mortality factors such as hunting, and are not directly comparable in most cases (Demarais et al. 2000). Ozoga (1969) reported that wild known-aged females in Michigan lived a maximum of 14 years. In this study, Key deer life expectancy was high despite high roadkill mortality observed in the population. A matrix model incorporating current survival and fecundity estimates predicts the average residency time to be 6.3 and 2.5 years for females and males, respectively (Chapter VII), which support survival estimates presented in this study.

Management Implications

The deer herd's restricted range and desire of the human population to develop its habitat results in interesting and challenging management problems. Nettles et al. (2001) reported the deer population on Big Pine and No Name keys are approaching or near carrying capacity based on observed abomasal parasite counts. Assuming high population densities, highway mortality might benefit the Key deer population by reducing the overall population size. In other words, highway mortality serves as an alternative form of predation or hunting for the Key deer. Despite the biological benefits in herd reduction, however, minimizing highway mortality is encouraged because of human safety concerns and because road mortality is an inhumane method of reducing deer numbers. Efforts to reduce road mortality should be concentrated in SBPK, particularly in the US 1 corridor. Future research should include documenting changes in survival, mortality, and population growth as deer densities continue to change, and a better understanding of fawn survival and recruitment.

CHAPTER III

HABITAT USE PATTERNS AND VEGETATION CHANGES

SYNOPSIS

Habitat loss and fragmentation is a concern in the recovery of the Key deer. With increasing urban development in the Florida Keys, an understanding of habitat requirements for this endangered deer population is needed. Key deer were radio-collared as part of 2 separate field studies conducted in 1968-72 (historic study) and 1998-00 (present study). The objectives of these studies were to (1) determine Key deer habitat use at different spatial scales, (2) evaluate changes in vegetation and identify vegetation types most threatened by development, and (3) provide guidelines to direct future land acquisition programs. Six vegetation types were described and used in this study: pineland, hammock, developed, freshwater marsh, buttonwood, and mangrove. Key deer habitat selection was evaluated by comparing percent use and the calculation of a habitat selection ratio (use/available). In addition, changes in vegetation types between periods (1800, 1955, 1970, 1985, 2000) and by island were determined using a GIS. A total of 180 (females, n = 96; males, n = 84) Key deer was radio-collared and monitored. Key deer selected vegetation in the following order (from preferred to avoided): pineland, hammock, developed, freshwater marsh, buttonwood, and mangrove. Key deer preferred upland vegetation types (> 1 m above mean sea level) while avoiding tidal or lower elevation areas (< 1 m above mean sea level). Key deer also preferred developed areas. Urban development benefits the deer population by the conversion of tidal areas (mangrove, buttonwood) considered marginal deer habitat to "upland" areas. However, continued development could have negative effects due to secondary impacts such as increases in road mortality or deer entanglement. Analyses of GIS coverages suggest that historically development threatened near-shore habitats. Recent trends, however, suggest that upland areas (pineland, hammock) are at a greater risk of being developed. Upland areas are important to Key deer and conservation measures (e.g., land acquisition and protection) of these areas are needed in the near future.

INTRODUCTION

Habitat loss and fragmentation due to urban development in the Keys is a concern in the recovery and management of Key deer (Klimstra et al. 1974, Folk 1991, USFWS 1999). Since

1970, the human population has increased nearly 10-fold on Big Pine and No Name keys (Chapter I). With increasing urban development in the Florida Keys, there is a need to understand the habitat needs of Key deer. Specifically, identification of vegetation types important to Key deer and threatened by development, provision of guidelines for the management of Key deer habitat, and directing land acquisition programs with this information would all aid in the recovery of this endangered deer population. Furthermore, a PVA (Akcakaya 2000) is currently being conducted as part of a HCP for Big Pine and No Name keys (Chapter I), and estimates of Key deer selection are needed for model implementation. Reliable information about Key deer habitat selection and carrying capacity for these 2 islands, however, is lacking.

The objective of this study was to gain an understanding of habitat use patterns of Key deer. Key deer were radio-collared as part of 2 separate field studies (Chapter I), and these data were used to address several study objectives: (1) determine Key deer habitat use at different spatial scales, (2) evaluate changes in vegetation and identify vegetation types most threatened by development, and (3) provide guidelines to direct land acquisition programs in the future. Terms used to describe habitat use or selection were defined as follows: (1) preferred – used in greater proportion to its availability, selected for, (2) avoided – not used in proportion to its availability, selected against, and (3) habitat use or selection – the preference or avoidance of vegetation types by an animal with use and selection being used interchangeably.

METHODS

Radio Telemetry

Key deer were radio-collared as part of 2 separate research projects conducted December 1968-June 1972, and January 1998-December 2000 on Big Pine and No Name keys. All telemetry data described in this chapter were collected on these 2 islands (Chapter I). Deer were captured throughout the study using portable drive nets, drop nets, and hand capture (Silvy 1975, Silvy et al. 1975, Lopez et al. 1998). Captured deer were marked in a variety of ways depending on sex and age. Methods used included plastic neck collars (8-cm wide, primarily females of all age-classes), leather antler collars (0.25-cm wide, yearling and adult males only), or elastic, expandable neck collars (3-cm wide, primarily male fawns/yearlings). A battery-powered mortality-sensitive radio transmitter (150-152 MHz, 100-110 g for plastic neck collars, 10-20 g for antler transmitters and elastic collars,

Advanced Telemetry Systems, Isanti, Minnesota, USA) was attached to collar material. In addition, each animal captured received an ear tattoo, which served as a permanent marker (Silvy 1975).

Radio-collared deer were monitored 6-7 times per week at random intervals (24-hour period was divided into 6 equal 4-hour segments; one 4-hour segment was randomly selected and during that time all deer were located, Silvy 1975). Deer locations were determined via homing and triangulation (Silvy 1975, White and Garrott 1990). Telemetry locations were inputted into ArcView GIS (Version 3.2) and Microsoft Access (Version 97).

Vegetation Mapping

Six vegetation types were described by Silvy (1975) and Hardin (1974) and used in this study: pineland, hammock, developed, freshwater marsh, buttonwood, and mangrove (Chapter I). Vegetation data were obtained from the Advanced Identification of Wetlands Project (MacAulay et al. 1994) and inputted into ArcView GIS (Version 3.2). Historical vegetation maps of Big Pine and No Name keys were obtained from previous studies (Dickson 1955, Silvy 1975, Folk 1991), in addition to aerial photography from 1955, 1970, 1985, and 1995. Reclassifying developed areas to previous vegetation types generated historical vegetation coverages. For example, in the construction of the 1985 vegetation map, development occurring between 1985-00 was reclassified on the 2000 coverage to the original vegetation types. Aerial photographs, vegetation maps, and ownership data (tax roll data queried to identify homes built between certain years) for that time period were used to validate reclassifications. Vegetation maps generated included 1800, 1955, 1970, 1985, and 2000 coverages (Chapter I).

Data Analysis

Habitat selection for radio-collared Key deer was evaluated by vegetation type, sex, island, and period (historic vs. current study). All age-classes were combined in the analysis due to small sample sizes (White and Garrott 1990). Only deer with $\geq$ 30 locations were used in evaluating habitat selection using the following criteria: (1) average percent use by vegetation type and (2) average selection ratio (preference/avoidance) by vegetation type. Percent use by vegetation type was determined for each radio-collared deer, and averaged by vegetation type for all animals. Solely the use of simple percentages in determining habitat selection might be problematic because a measure of available habitat is not considered (Johnson 1980, White and Garrott 1990). In order to address this problem, a habitat selection ratio, which incorporates habitat availability in the analysis, also was used.

A habitat selection ratio was calculated by dividing observed use by availability for each deer and vegetation type. Observed use by vegetation type was determined from radio telemetry locations for each animal. An estimate of availability was determined by multiplying the proportion of a given vegetation type in the study area or animal's home range to the total radio locations observed. To illustrate the calculation of the habitat selection ratio, a simple example is presented. If a radio-collared deer was observed 100 times in Habitat A (vegetation type comprises 25% of the study area) from a total of 500 radio locations, the expected number of locations (availability) for Habitat A, assuming no selection, would be 125 (500 locations x 0.25). The selection ratio (*S*) was then calculated by

$$S = \left(\frac{U + 0.001}{A + 0.001} \right)$$

where *U* is equal to observed use and *A* is equal to expected use (availability). In order to avoid a zero in the numerator or denominator, 0.001 was added to both use and availability (Aebischer et al. 1993). In this example, the selection ratio was 0.8 (100.001/125.001) suggesting this animal avoided Habitat A (ratio < 1). Selection ratios > 1 would suggest preference by an animal. When comparing use in the form of an animal's home range (e.g., Johnson's second-order selection, range vs. study area, see below), total radio locations were multiplied by the proportion of each vegetation type. For example, assuming Habitat A comprised 35% of an animal's home range, the total number of locations, say 300, is multiplied by that proportion. Thus, the estimate of deer use would be 105 (300 locations x 0.35). Assuming this vegetation type comprised 25% of the total study area, the expected use or availability would be 75 (300 locations x 0.25). In this example, a selection ratio of 1.39 (105.001/75.001) suggests this vegetation type was preferred (ratio > 1).

Using selection ratios as described above, habitat selection was evaluated for Key deer at 3 spatial scales. First, vegetation types of locations were compared to vegetation types for the entire island or study area (also called point-study area selection). This comparison is analogous to the first-order selection described by Johnson (1980). Second, vegetation types in each deer's 95% minimum convex polygon range were compared to vegetation types for the entire island or study area (also called range-study area selection) (White and Garrott 1990). This comparison is analogous to Johnson's (1980) second-order selection. Finally, vegetation types of locations were compared to vegetation types available within each deer's 95%

minimum convex polygon range (Johnson's third-order selection, also called points-range selection). Evaluation of habitat use at different selection levels reduces potential effects from arbitrarily defining what is perceived to be available to an animal (Porter and Church 1987). Furthermore, a multi-scale approach provides additional insight in how animals use habitat at different scales (Aebischer et al. 1993, Garshelis 2000).

For each selection order, differences in selection ratios were tested by sex, island, period, and vegetation type (independent variables) using an ANOVA (Ott 1993). Tukey's HSD for multiple comparisons was used to separate means when *F*-values were significant ($P \leq 0.05$). Aebischer et al. (1993) identified 4 problems in analyzing habitat use data: (1) inappropriate designation of experimental unit, (2) non-independence of proportions, (3) differential habitat use by groups of individuals, and (4) arbitrary definition of habitat availability. The approach used here addresses many of these concerns. For example, many analyses take radio locations as the sampling unit rather than the animal (e.g., Neu et al. 1974, Byers et al. 1984, Problem 1). By calculating selection ratios for each animal, the sampling unit used here is the individual animal. Use of proportions to describe habitat composition are considered to be non-independent because an animal's proportional use of one habitat type is linked to other habitat types (e.g., Friedman 1937, Quade 1979, Problem 2). Use of a habitat selection ratio overcomes this problem because the sum of the individual ratios does not sum to 1 (unit-sum constraint). Third, animals within a population might fall into distinct categories (e.g., sex, age, area), that cannot be evaluated using other methods (e.g., Friedman 1937, Neu et al. 1974, Byers et al. 1984, Quade 1979, Johnson 1980, Problem 3). The approach used here uses an ANOVA, which allows between-group differences to be tested. Finally, a multi-scaled approach was used in which the animal defines what is available (Problem 4).

Vegetation changes between periods (1800, 1955, 1970, 1985, 2000) and by island were evaluated using spatial data entered into the GIS. The number of houses constructed and an estimate habitat loss due to development (i.e., "footprint" from homes/businesses, space unavailable to deer) by period and island were determined from the Monroe County tax roll (Monroe County Growth Management Division 1992). Finally, an estimate of edge density (m) at a landscape-scale was determined with patch analyst in ArcView.

RESULTS

Habitat Use

A total of 180 (females, n = 96; males, n = 84) radio-collared Key deer was used in the analysis (Table 3.1). A total of 40,248 radio locations was used; an average of 222 (SD = 176, range = 30-743) locations per animal. In terms of average percent use by vegetation type, deer used upland areas (pineland, hammock, developed) more (range 20-35%) than wetland areas (buttonwood, freshwater marsh, mangrove, range 7-9%, Table 3.2, Fig. 3.1).

Analyses of habitat selection ratios found vegetation type was significant ($P < 0.001$) while sex, island, and period were less predictive (P = 0.064-0.970) in describing Key deer habitat use patterns for most selection orders (Table 3.3, Fig. 3.2). In comparing points to study area, uplands were preferred (ratio > 1), whereas wetlands were avoided (ratio < 1). Similar relationships were found for range-study area selection and points-range selection. Though the degree of selection and/or order varied, in general pineland, hammock, and developed were preferred, whereas buttonwood and mangrove were avoided (Table 3.3, Fig. 3.2).

Vegetation Changes

Since 1940, approximately 641 ha (21% of total area) has been developed on Big Pine (610 ha, 24%) and No Name (31 ha, 7%) keys (Figs. 3.3-3.10). Approximately 460 ha are considered unavailable (year 2000) to deer due to the “footprint” of homes/businesses (Fig. 3.11). The largest land conversion or clearing (e.g., large subdivisions) occurred during the 1970-80’s, while the largest influx of home building occurred in the early and late 1980’s. Initially, conversion of vegetation types was in mangrove and buttonwood areas but eventually increased in pineland and hammock areas. Despite the increase in total upland area, the amount of useable upland area (total upland area – development footprint = useable upland area) and edge density, both of which are considered beneficial for white-tailed deer (McShea et al. 1997, Demarais et al 2000), can be described as hyperbolic (Figs. 3.11-3.14). For these reasons, it is hypothesized the relationship between deer densities and urban development also is hyperbolic (Fig. 3.15)

Table 3.1. Demographics of 180 radio-collared Florida Key deer on Big Pine and No Name keys, 1968-72 and 1998-00.

Period Sex	Big Pine	No Name	Total
Present			
Female	46	17	63
Male	48	20	68
Total	94	37	131
Historic			
Female	21	0	21
Male	28	0	28
Total	49	0	49
Grand Total	143	37	180

Table 3.2. Key deer use (%) and range composition (%) by vegetation type, Big Pine and No Name keys, 1968-72 and 1998-00.

Sex	Type	*n*	Θ	SE
% Use				
Females	PL	84	36.4	3.4
	HM	84	24.9	3.0
	DV	84	19.1	1.9
	BW	84	7.7	1.1
	FM	84	6.3	1.1
	MG	84	5.6	1.0
Males	PL	96	32.8	2.7
	DV	96	20.7	1.8
	HM	96	20.6	2.2
	BW	96	10.4	1.2
	MG	96	8.7	1.0
	FM	96	7.0	1.2
Combined	PL	180	34.5	2.1
	HM	180	22.6	1.8
	DV	180	19.9	1.3
	BW	180	9.1	0.8
	MG	180	7.3	0.7
	FM	180	6.6	0.8
% Range				
Females	PL	84	31.7	2.4
	DV	84	19.3	1.1
	HM	84	18.1	2.3
	MG	84	12.2	1.5
	FM	84	11.7	1.4

Table 3.2. Continued.

Sex	Type	*n*	Θ	SE
	BW	84	7.1	0.6
Males	PL	96	30.3	2.0
	DV	96	20.2	1.2
	HM	96	16.3	1.9
	FM	96	13.1	1.3
	MG	96	12.4	1.3
	BW	96	7.7	0.6
Combined	PL	180	30.9	1.5
	DV	180	19.8	0.8
	HM	180	17.1	1.5
	FM	180	12.5	1.0
	MG	180	12.3	1.0
	BW	180	7.4	0.4

Table 3.3. Key deer habitat use (Θ = mean use/availability ratio) by vegetation type at 3 different spatial scales, Big Pine and No Name keys, 1968-72 and 1998-00.

Scale								
Sex	Type	*n*	Θ	SE	Island	Period	Sex	Type
Points-Study Area								
Combined	PL	180	1.688	0.109	A	A	A	A
	HM	180	1.581	0.139	A	A	A	AB
	DV	180	1.205	0.089	A	A	A	BC
	FM	180	0.893	0.121	A	A	A	CD
	BW	180	0.802	0.074	A	A	A	D
	MG	180	0.284	0.028	A	A	A	E
	$F_{1,5}$				3.44	0.00	0.07	27.65
	P				0.064	0.970	0.792	0.000
Ranges-Study Area								
Combined	PL	180	1.480	0.073	A	A	A	A
	FM	180	1.464	0.096	A	A	A	A
	DV	180	1.236	0.049	A	A	A	AB
	HM	180	1.019	0.075	A	A	A	B
	BW	180	0.646	0.040	A	A	A	C
	MG	180	0.487	0.040	A	A	A	C
	$F_{1,5}$				2.35	0.38	0.03	39.95
	P				0.125	0.537	0.864	0.000
Points-Ranges								
Females	HM	84	1.306	0.170				
	BW	84	1.026	0.140				
	PL	84	0.951	0.079				
	DV	84	0.935	0.082				
	MG	84	0.482	0.070				
	FM	84	0.451	0.095				

Table 3.3. Continued.

Scale								
Sex	Type	*n*	0	SE	Island	Period	Sex	Type
Males	FM	96	1.462	0.162				
	PL	96	1.331	0.339				
	DV	96	1.248	0.142				
	HM	96	1.018	0.088				
	MG	96	0.783	0.096				
	BW	96	0.434	0.060				
Combined	HM	180	1.389	0.117	A	A		A
	PL	180	1.154	0.185	A	A		A
	BW	180	1.144	0.099	A	A		A
	DV	180	0.979	0.060	A	A		AB
	MG	180	0.643	0.062	A	A		B
	FM	180	0.442	0.054	A	A		B
	$F_{1,5}$				0.12	0.88	4.42	11.00
	P				0.730	0.348	0.036	0.000

[a]*F* and *P* values are for overall comparisons.

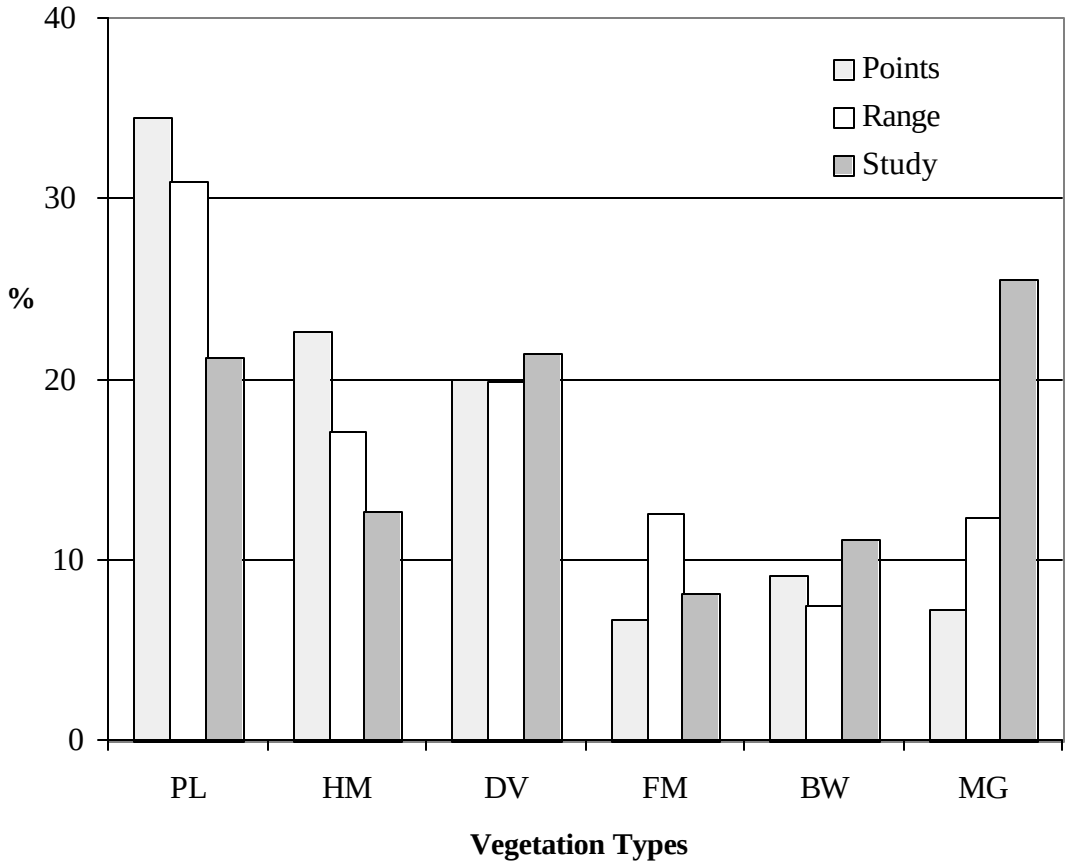


Fig. 3.1. Percent use (radio locations), range composition, and study area composition by vegetation type for Key deer on Big Pine and No Name keys.

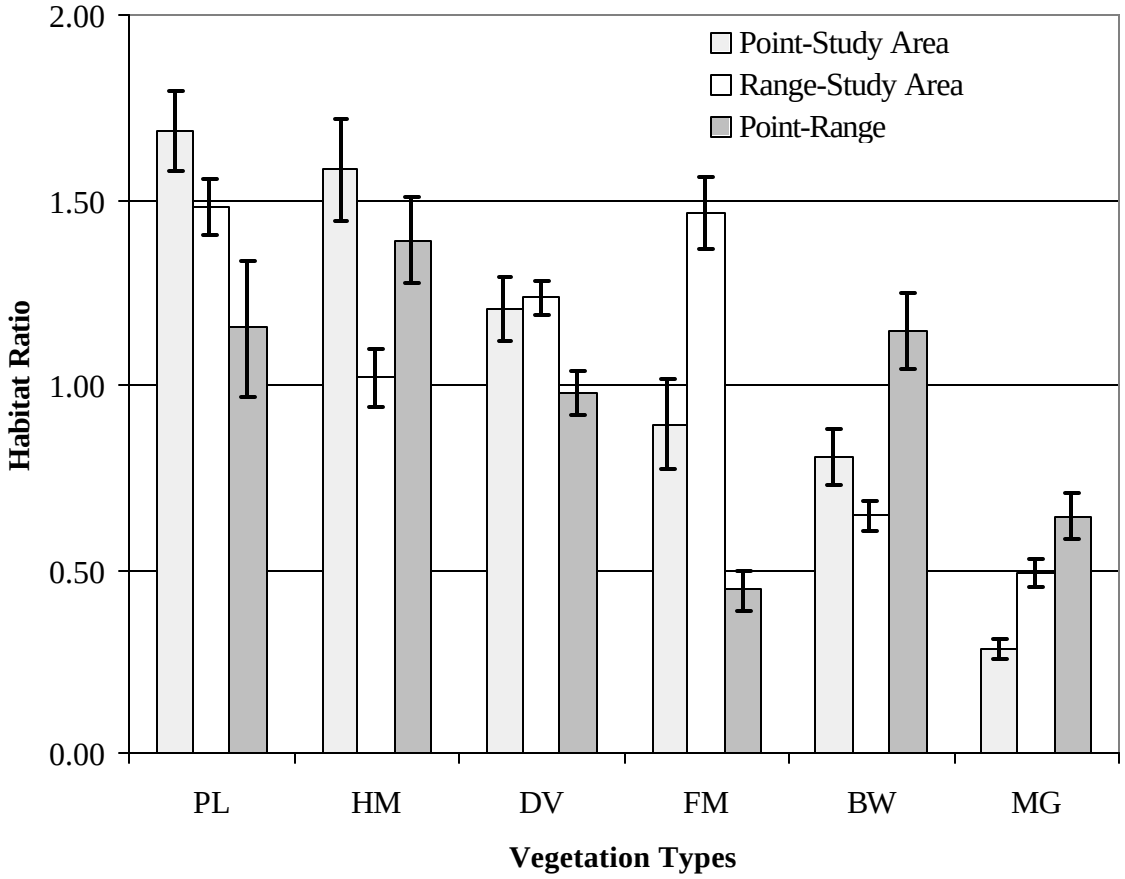


Fig. 3.2. Habitat selection ratios (use/available, < 1 avoided, > 1 preferred) for radio-collared Key deer by vegetation type at 3 different spatial scales.

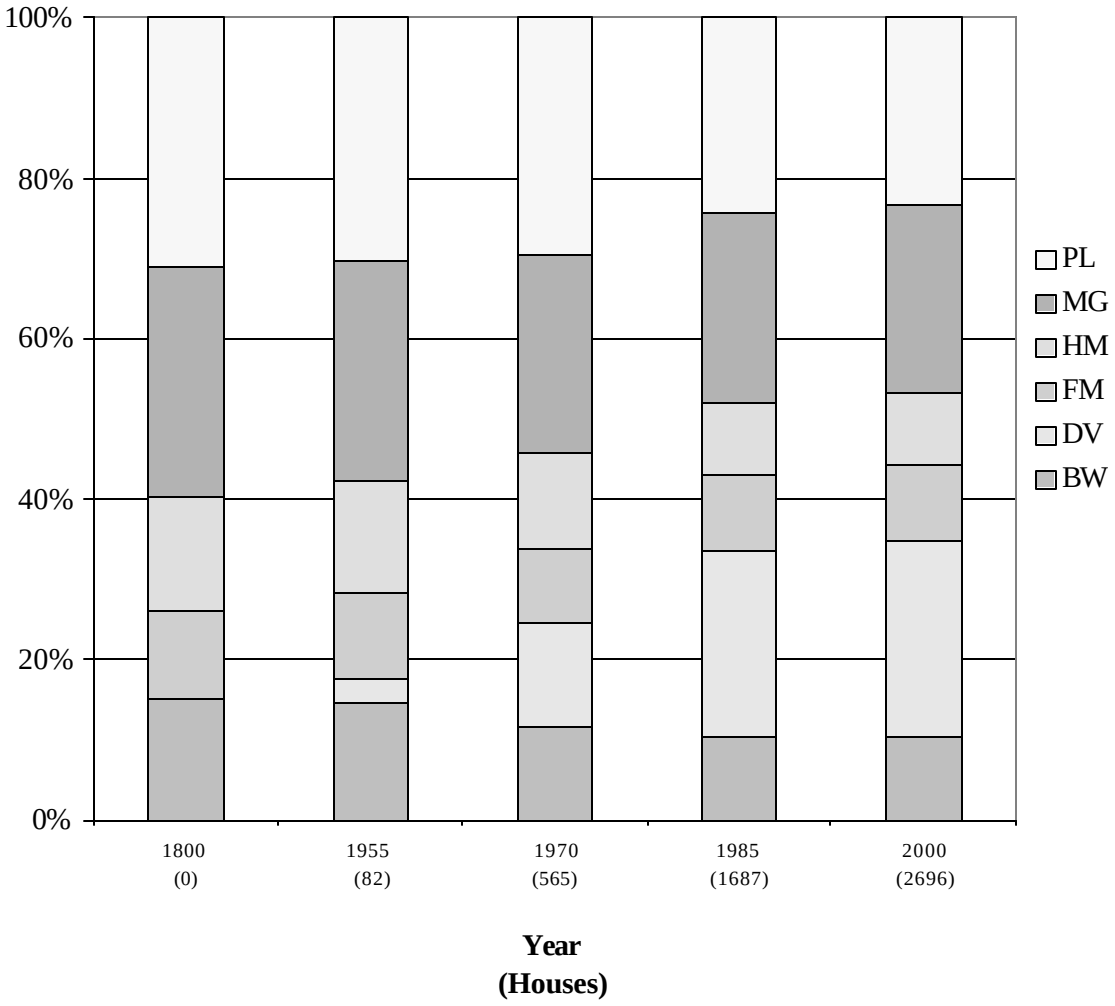


Fig. 3.3. Percent composition of vegetation types by year for Big Pine Key (number of houses in parentheses).

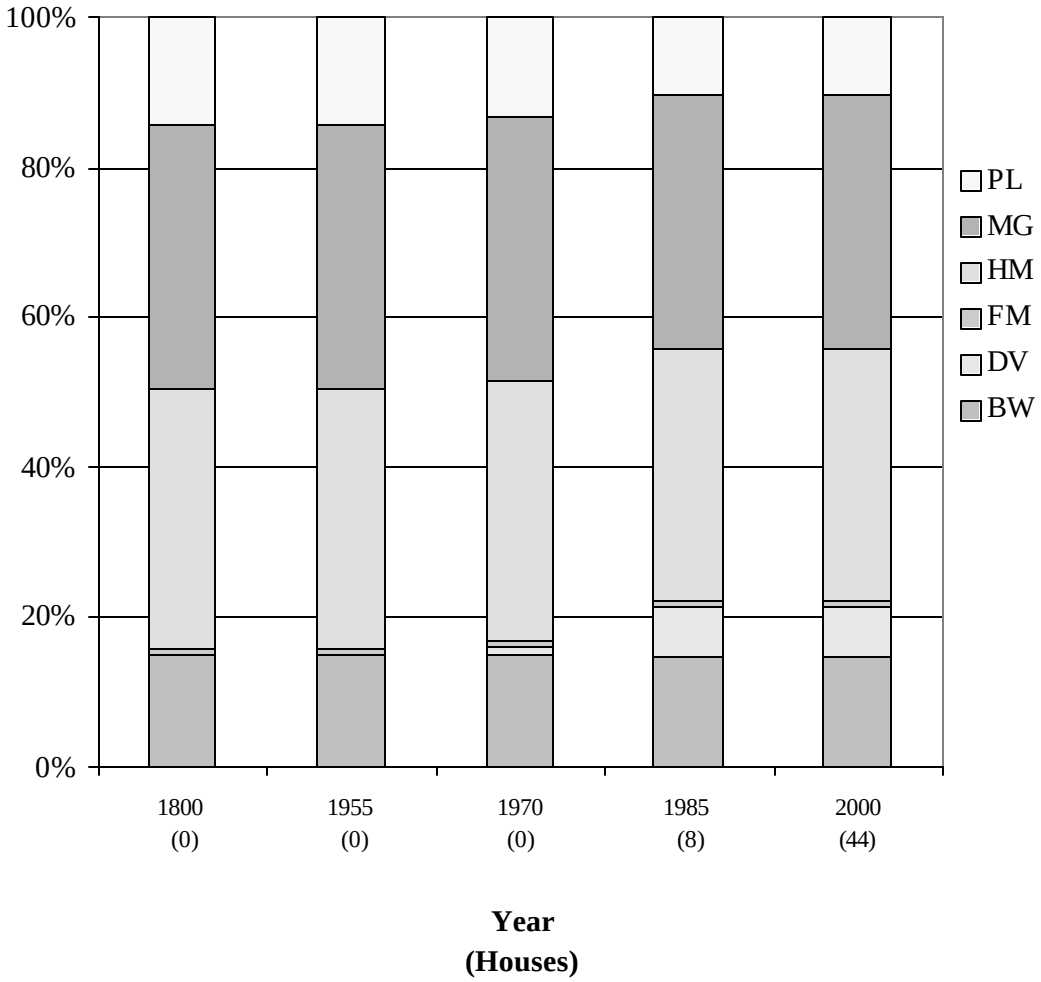


Fig. 3.4. Percent composition of vegetation types by year for No Name Key (number of houses in parentheses).

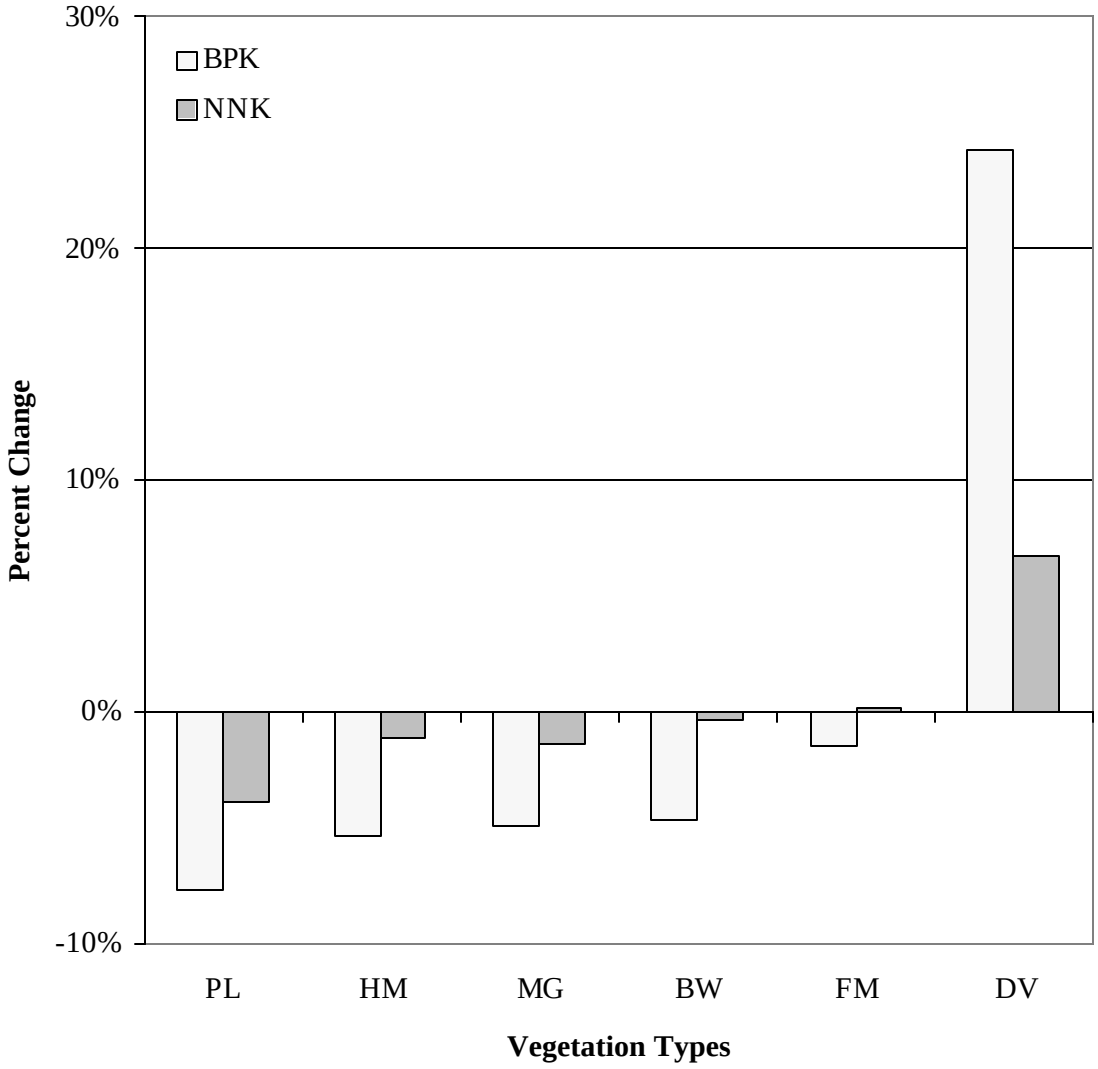


Fig. 3.5. Percent change in vegetation type for Big Pine and No Name keys between 1800 and 2000.

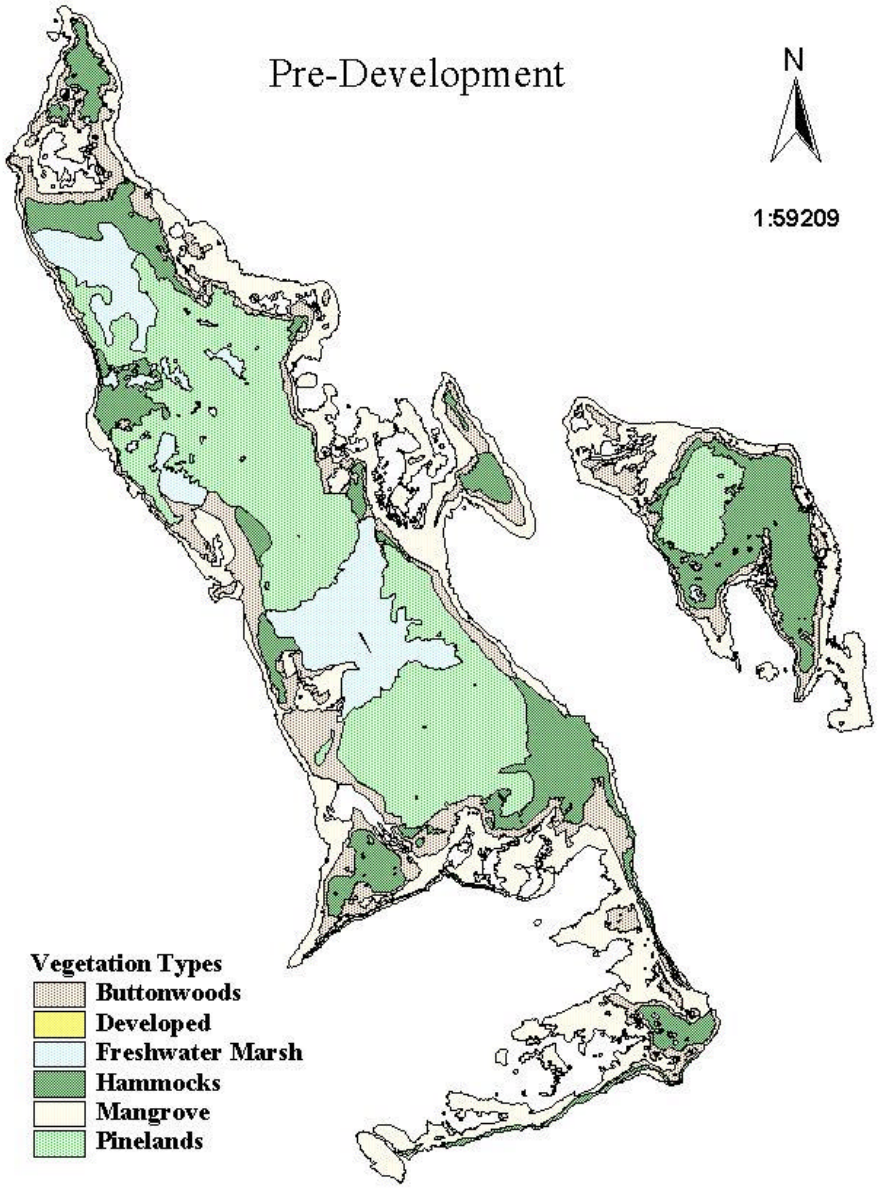


Fig. 3.6. Vegetation types for Big Pine and No Name keys, 1800.

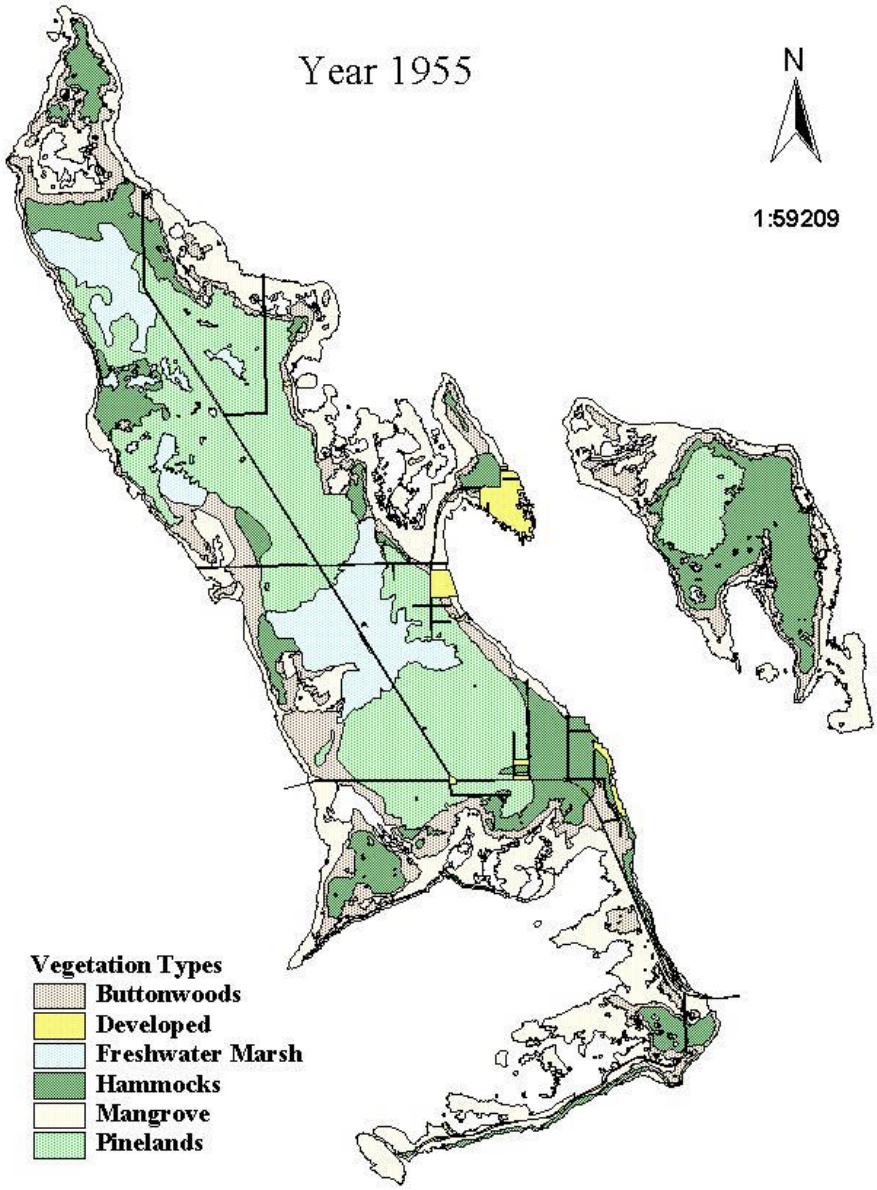


Fig. 3.7. Vegetation types for Big Pine and No Name keys, 1955.

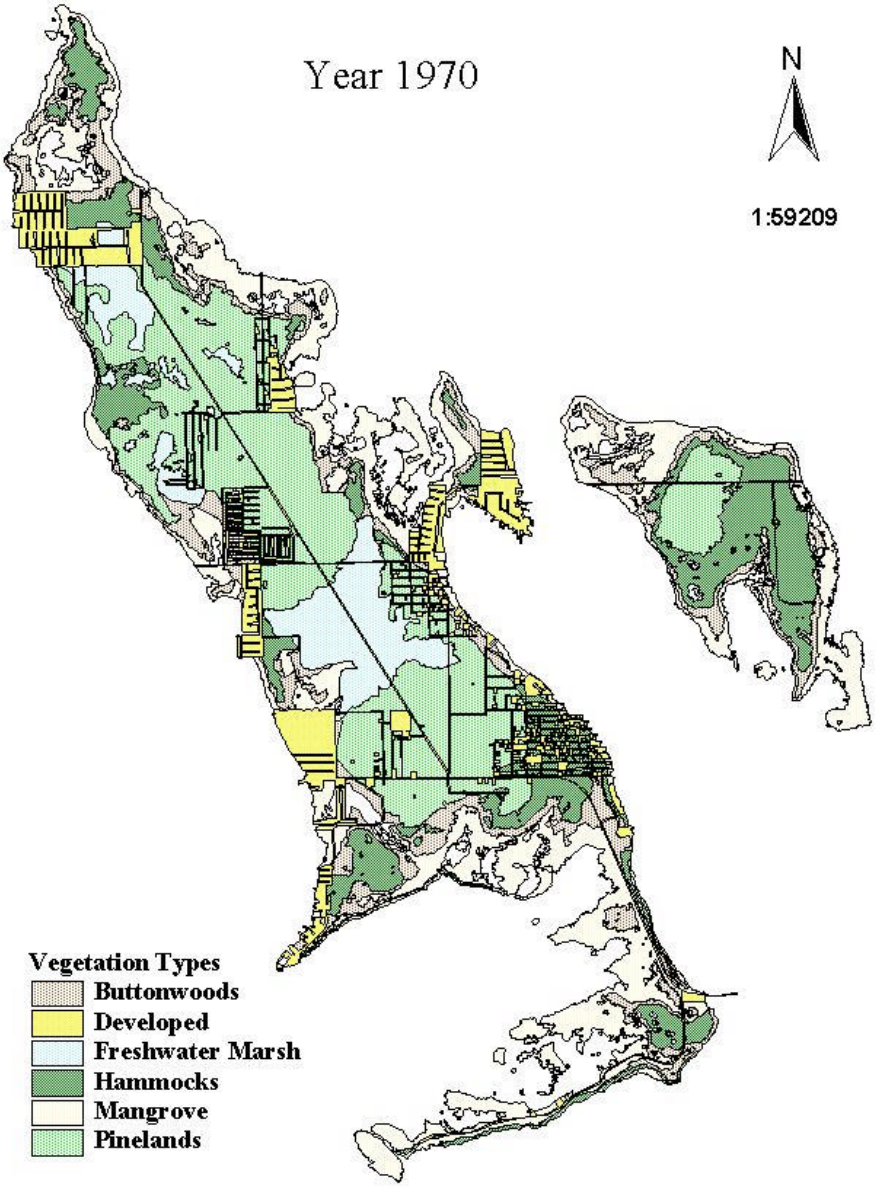


Fig. 3.8. Vegetation types for Big Pine and No Name keys, 1970.

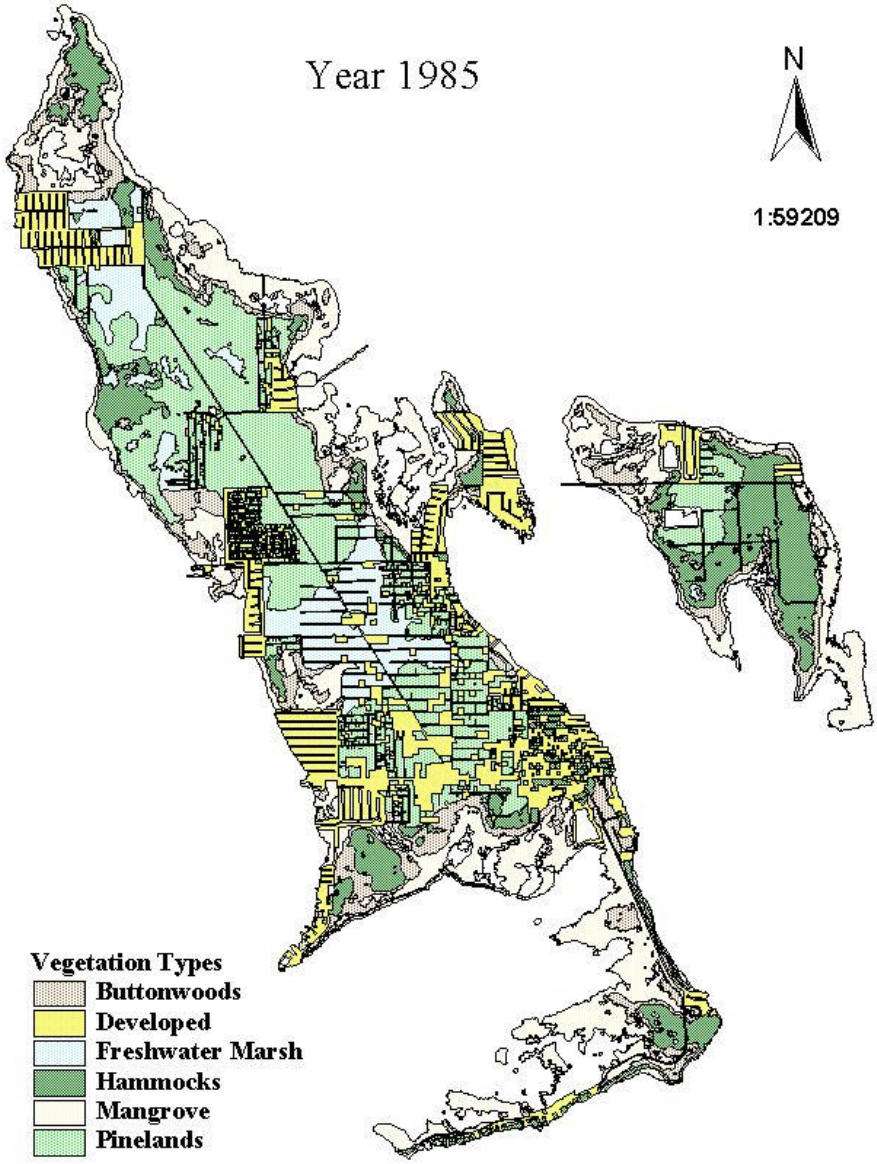


Fig. 3.9. Vegetation types for Big Pine and No Name keys, 1985.

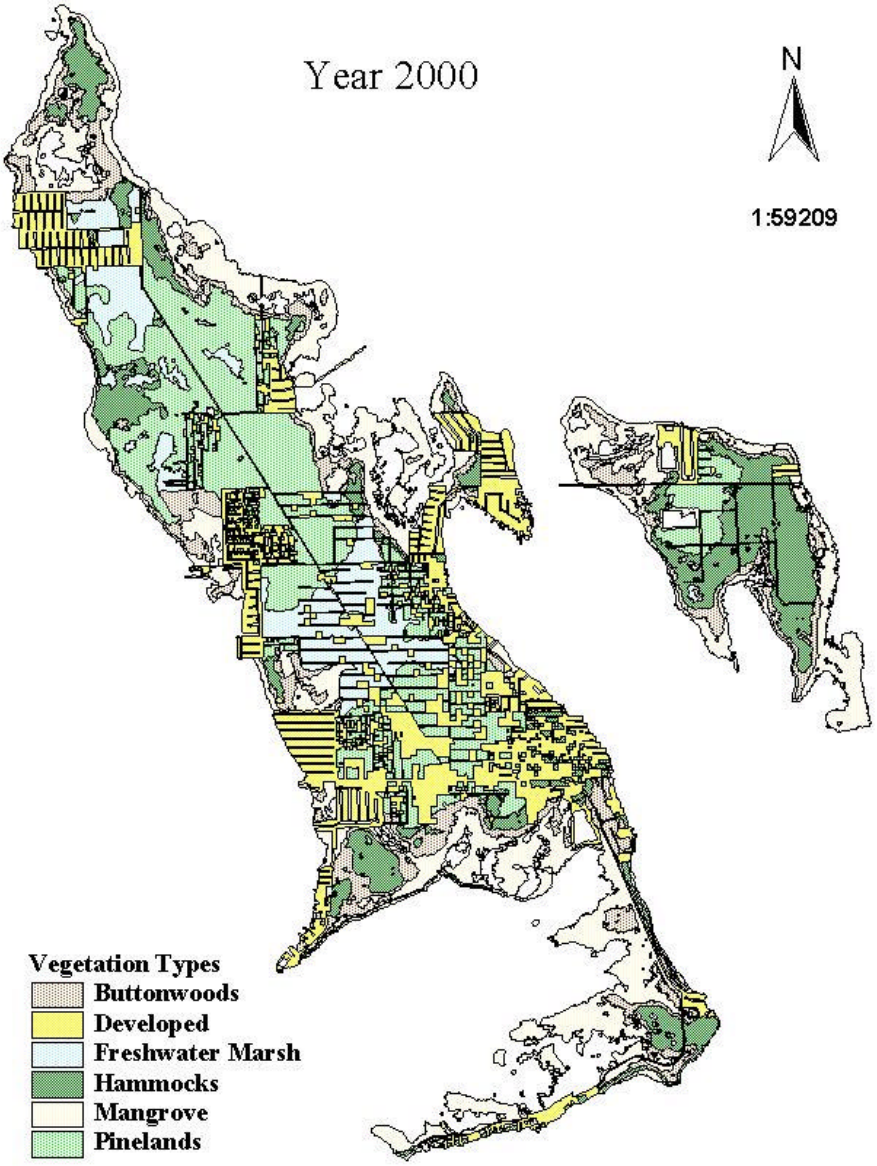


Fig. 3.10. Vegetation types for Big Pine and No Name keys, 2000.

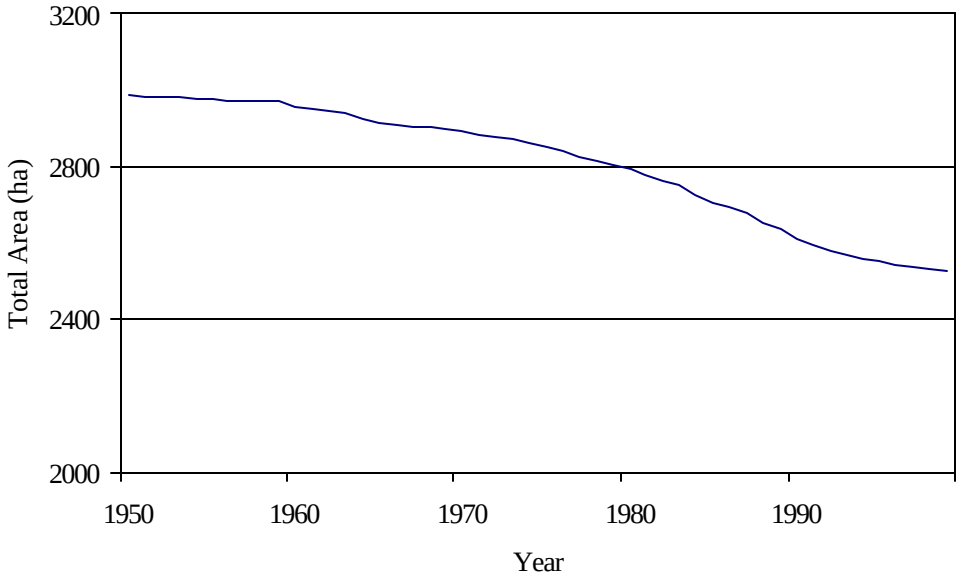


Fig. 3.11. Annual changes in total available area (ha) due to development (total area – "footprint" of homes/businesses = total available area) for Big Pine and No Name keys, 1950-00.

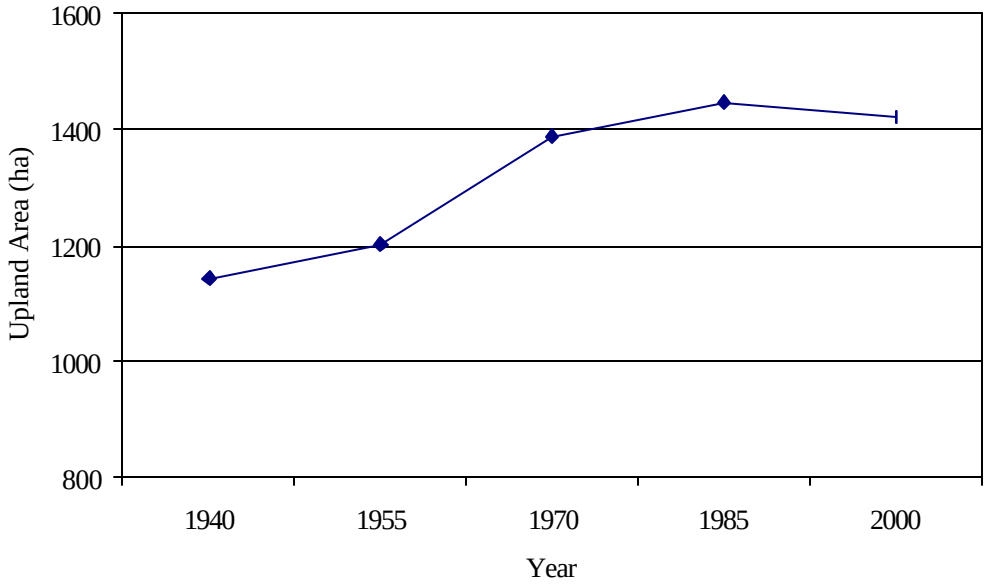


Fig. 3.12. Annual changes in total upland area (pineland, hammock, development, ha) for Big Pine and No Name keys, 1940-00.

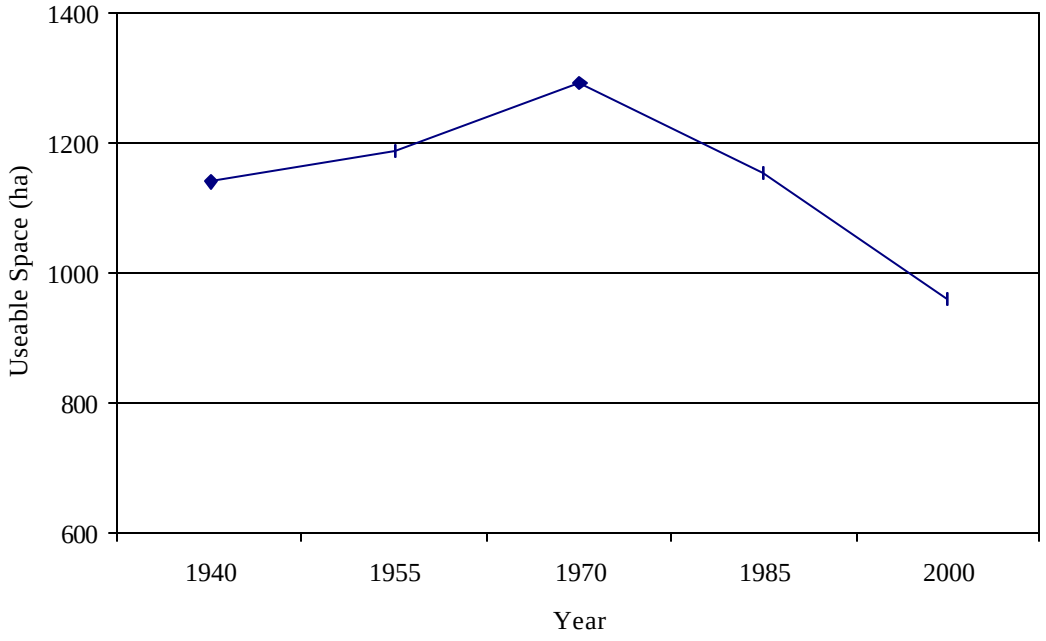


Fig. 3.13. Annual changes in total useable upland area (total upland area – "footprint" of homes/businesses = useable upland area) for Big Pine and No Name keys, 1940-00.

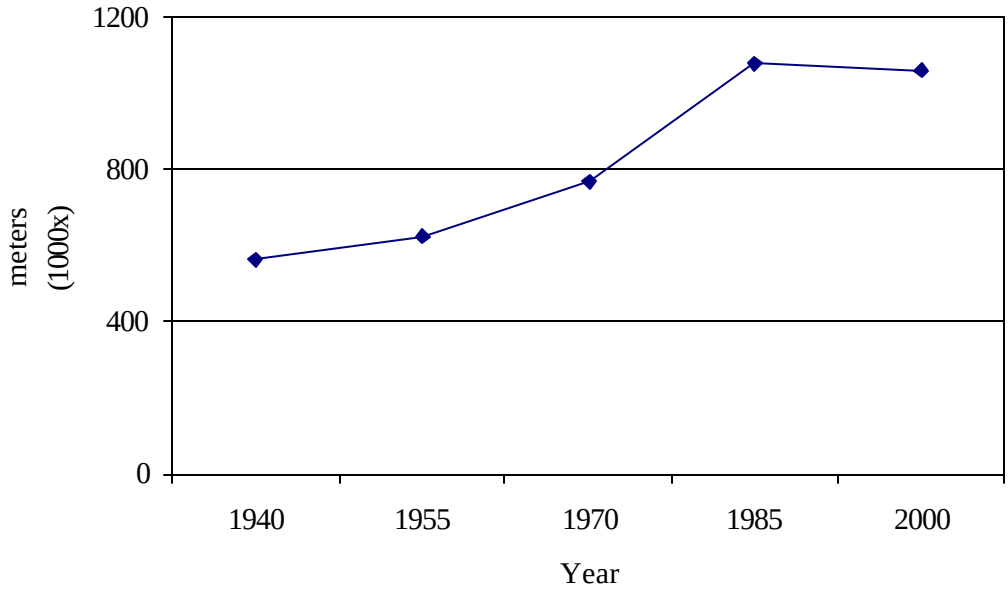


Fig. 3.14. Annual changes in total edge density (m) for Big Pine and No Name keys, 1940-00.

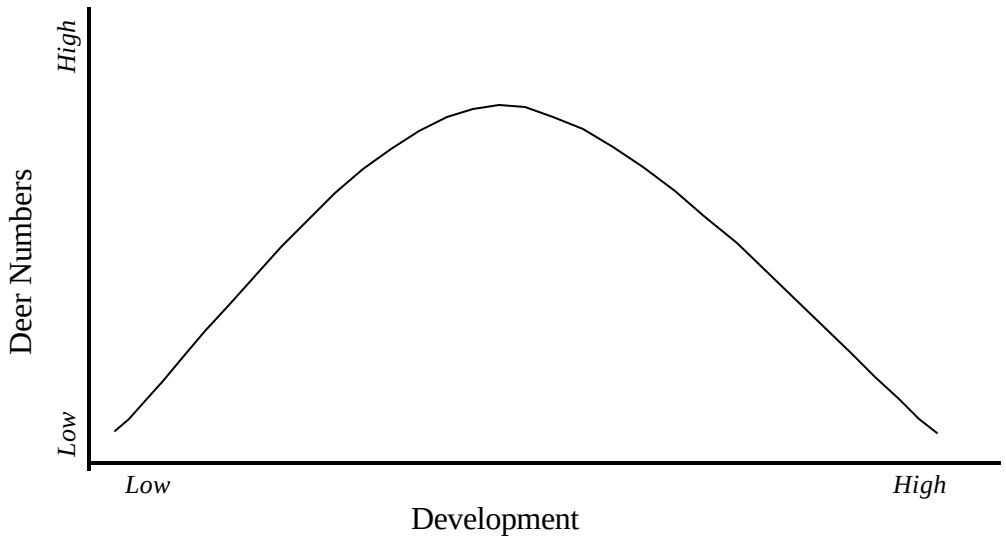


Fig. 3.15. Conceptual model illustrating the impacts of development on the Key deer herd.

DISCUSSION

Habitat Use

Key deer preferred upland habitat types (> 1 m above mean sea level) over tidal or lower elevation areas (< 1 m above mean sea level). The importance of upland areas, particularly pinelands and hammocks, in providing necessary resources for the Key deer has been well documented in previous studies (Klimstra et al. 1974, Silvy 1975, Folk 1991). For example, freshwater is important to the survival of Key deer, and is typically limited to these upland habitat types (pineland, hammock, Folk 1991). Approximately 58% of permanent freshwater sources within the Key deer range occur in these 2 vegetation types (Chapter I). Uplands also serve as important fawning areas; Hardin (1974) found that approximately 85% of Key deer fawning occurred in pinelands and hammocks. Finally, islands with high deer densities are those with a substantial upland component while islands that are mostly tidal (e.g., Summerland, Ramrod) support fewer deer than similar-sized islands with more upland areas (e.g., No Name Key, Little Pine Key, R. R. Lopez, TAMU, unpublished data, Chapter I). For these reasons, it is not surprising that Key deer selected uplands (pinelands, hammocks) and avoided tidal areas (mangroves, buttonwoods).

Two observations in the analysis are also worth mentioning. First, the variation in degree of selection for freshwater marsh among selection orders can be attributed to potential biases in availability (e.g., No Name Key has < 4 ha of freshwater marsh). In order to correct this potential bias, combining vegetation types with small areas with other similar areas is recommended. It is important to note that freshwater marsh is an important source of freshwater to Key deer (Folk 1991). The actual time spent using resources in freshwater marsh might be lower than other habitat types such as pinelands and hammocks. The statistical insignificance of freshwater marsh is likely due to the methods used to analyze habitat selection, thus, the importance of this habitat type to the Key deer should not be underestimated. Second, a differential habitat selection between sexes ($P = 0.036$) at the points-range selection scale was observed (Table 3.3). These differences might be explained by differences in the amount of available habitat between traditional deer range distributions. For example, survey data suggests the majority of females (75%) occupy the northern end of Big Pine Key, whereas the majority of males (64%) occupy the southern end of the island (Chapters I and VI). Habitat availability between the northern and southern ends of Big Pine differ (Fig. 3.10), which might explain differences in selection observed between sexes.

Vegetation Changes

Since 1940, development has increased 7 and 24% on No Name and Big Pine keys, respectively (Figs. 3.3-3.10). Analysis of GIS data suggests that historically lowland habitats were threatened by development. Historic losses in tidal areas were attributed to the desire of developers to build homesites with water access. Since the enactment of federal and state laws such as the Florida Mangrove Protection Act (1985), development of these vegetation types has been restricted (Gallagher 1991), resulting in development of upland areas (pineland, hammock) in more recent years (Figs. 3.6-3.10). Upland areas are important to the Key deer requiring conservation (e.g., land acquisition and protection) of these areas in the near future.

Impacts of Development

It is hypothesized that urban development historically benefited the Key deer; however, it is proposed the negative impacts from development would eventually outweigh the positive benefits with continued development. Historically, urban development benefited the deer by the conversion of tidal areas (mangrove, buttonwood), which are considered marginal deer habitat, to "upland" areas capable of supporting greater numbers of deer. In other words, the "carrying-capacity" for marginal vegetation types improved due to higher elevations in subdivisions and the planting of ornamental plants within these areas. Benefits from development included an increase in total upland area (Fig. 3.12), and an increase in total edge density or habitat quality for white-tailed deer (Fig. 3.14, McShea et al. 1997, Demarais et al 2000). Since the mid-1970's, when the last major subdivisions were dredged and filled, home construction or the "infilling" of subdivisions continued (Fig. 3.11). Unlike land clearing that occurred between 1940-75, current development (i.e., building of homes) on scarified lots offer little to no benefit to the deer population. Negative impacts include a decrease in total "useable" upland area (Fig. 3.13), a decrease in total edge density (Fig. 3.14), and an increase in secondary impacts such as road mortality and deer entanglement (Chapter II). Conceptually, the relationship between deer densities and the impact of urban development is described as hyperbolic; initially, the positive benefits of development outweigh the negative impacts up to a point. Beyond this inflexion point, the negative impacts of development begin to outweigh the positive benefits (Fig. 3.15).

Land Acquisition

Future land acquisition should target upland habitats to ensure the long-term viability of the Key deer. This recommendation is not intended to discourage the purchase of tidal areas; rather, it is meant to direct land acquisition efforts to potentially threatened habitats. Furthermore, the construction of a spatially-explicit PVA model would aid in determining recommendations for the amount of development (i.e., the location along the curve, Fig. 3.15) and potential areas to develop.

CHAPTER IV

POPULATON DENSITY AND STRUCTURE

SYNOPSIS

Intense hunting pressure and habitat loss reduced the Key deer numbers to an estimated 25-50 animals in the late 1940's. With the decrease in illegal hunting and the conservation of Key deer habitat, the deer population grew to an estimated 360-375 animals by 1972, the last official survey. Trend data collected by NKDR biologists suggests the deer population might have increased since then, however, reliable estimates of the density and structure of the deer population are lacking. Thus, the study objectives were to (1) estimate current population densities, sex ratios, and fawn:doe ratios on Big Pine and No Name keys and comparisons to historic estimates, and (2) evaluate the precision of survey methodology and outline a protocol for future monitoring. Road counts were conducted using 5 different routes on Big Pine and No Name keys from January 1969-March 2001. Three estimates describing the Key deer population were obtained from survey data: (1) population density, (2) female:male sex ratios, and (3) fawn:doe ratios. Survey route data (n = 301) suggests the Key deer population on Big Pine and No Name has increased by 240% since 1972 to an estimated 450-515 deer. In reviewing sex ratio estimates, a female:male sex ratio of about 2:1 was observed. This skewed sex ratio might be explained by (1) observer bias, particularly from USFWS counts, and (2) differential survival between sexes. In comparing fawn:doe ratio estimates by season, the highest average fawn:doe ratio observed was in early fall (October), with 0.39 fawns per doe being observed. In general, fawn:doe estimates were lowest in spring and summer and gradually increased in the fall and winter. This is not surprising due to the fact the peak fawning season for Key deer is 1 April, and fawns born in the spring and summer are not seen along survey routes until several months later. Findings from the study suggest that urban development might have benefited the deer population through land clearing, however, it is proposed that continued development might not have the same positive impacts observed from the past.

INTRODUCTION

Intense hunting pressure and habitat loss resulted in a decline in the Key deer population to an estimated 25-50 animals by the late 1940's (Dickson 1955, USFWS 1999). With the reduction of illegal hunting and the conservation of Key deer habitat through the establishment of the NKDR in 1957, the deer population grew to an estimated 360-375 animals by 1972, the last official survey (Silvy 1975). Trend data collected by USFWS biologists suggest the deer population might have increased since then, however, estimates of the density and structure of the deer population are lacking. This information would be useful in the management of the deer herd and in the proposed reclassification of the Key deer from endangered to threatened (USFWS 1999). Thus, reliable estimates of the current deer status (population density) are needed in the Key deer's recovery.

Key deer were radio-collared as part of 2 separate field studies (historic, 1968-72 and present, 1998-00) which included weekly survey routes that estimated deer density on Big Pine and No Name keys. In addition, trend survey data also were collected by USFWS biologists on these 2 islands between 1975-00. Collectively, these data were used to address the following study objectives: (1) estimate current population densities, sex ratios, and fawn:doe ratios on Big Pine and No Name keys and compare to historic estimates, and (2) evaluate precision of survey methodology and outline a protocol for future monitoring.

METHODS

Survey Types

Road counts were conducted from January 1969-March 2001 on Big Pine and No Name keys (Chapter I, Table 4.1, Fig. 4.1). Data were analyzed from 5 survey routes: (1) Big Pine Key 10-mile survey (hereafter BPK10m), (2) Big Pine Key 44-mile survey (hereafter BPK44m), (3) USFWS fall survey (hereafter FWS Fall), (4) USFWS monthly survey (hereafter USFWS), and (5) No Name Key survey (hereafter NNK). These surveys were designed to provide an index to the population size and structure of Key deer (number, sex, and age of deer seen were recorded for all survey types). Only the BPK44m and NNK surveys were designed to estimate deer density on the islands using a Lincoln-Peterson index as described by White and Garrott (1990). The BPK10m route, which was originally designed to survey the deer population on the NKDR (Silvy 1975), covers the northern half of Big Pine Key where the majority of property (> 85%) is owned and managed by the refuge (Chapter I). In 1971, the BPK44m route was

Table 4.1. Survey routes on Big Pine and No Name keys, 1969-01.

Survey route	Frequency	Years	Distance (km)	Start time
Big Pine Key 10-mile	Weekly	1969-72	16	½ hour before sunrise
(BPK10m)		1998-01		1½ hours before sunset
				1 hour after dark
Big Pine Key 44-mile	Weekly	1969-72	71	½ hour before sunrise
(BPK44m)		1998-01		1½ hours before sunset
USFWS annual counts	Monthly	1975-01	56	1 hour after dark
(USFWS)				
USFWS fall counts	5-7 nights	1988-01	56	1 hour after dark
(FWS Fall)	(October)			
No Name Key	Weekly	1998-01	4	½ hour before sunrise
(NNK)				1½ hours before sunset
				1 hour after dark

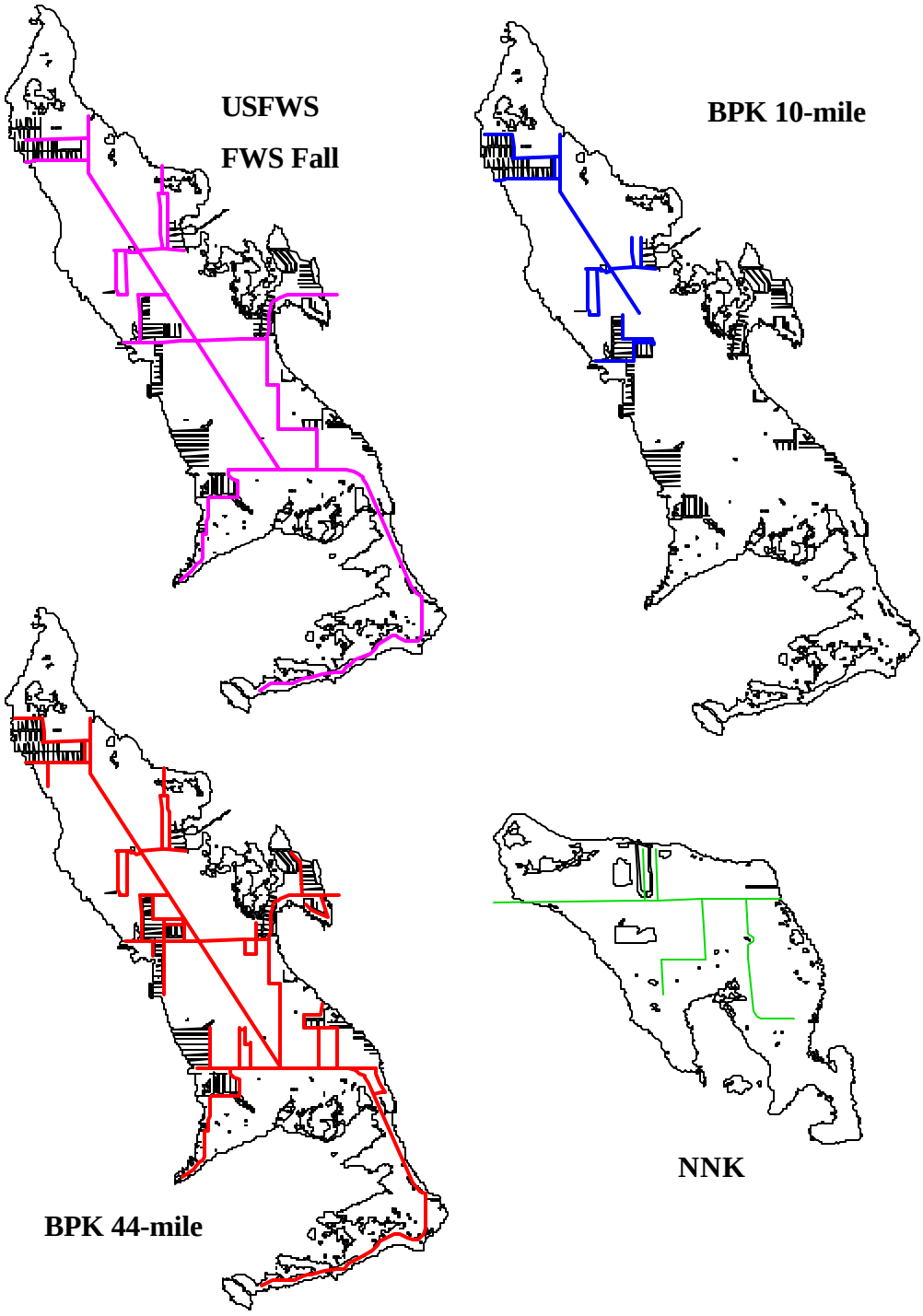


Fig. 4.1. Key deer survey routes on Big Pine and No Name keys.

established to survey all of Big Pine Key and includes data collected from the BPK10m survey (Fig. 4.1, Silvy 1975). In 1975, the USFWS official survey was established (modified from the BPK44m) and used by NKDR biologists to survey the deer population. In 1988, USFWS biologists began intense (5-7 nights) October counts along the original USFWS route. This survey, referred to as the FWS fall survey, was designed primarily to estimate fawn production (fawn:doe ratio estimates). Both the USFWS and FWS fall surveys included 3-km of roads on No Name Key, which were not included in the analysis to allow comparison to other survey routes.

Radio Telemetry

Deer were captured throughout the study using portable drive nets, drop nets, and hand capture (Silvy 1975, Silvy et al. 1975, Lopez et al. 1998). Captured deer were marked in a variety of ways, including plastic neck collars (8-cm wide, primarily females of all age-classes), leather antler collars (0.25-cm wide, yearling and adult males only), or elastic expandable neck collars (3-cm wide, primarily male fawns/yearlings). Collars on Key deer served as visual markers used in determining population estimates for Big Pine and No Name keys. The number of marked animals (number of deer available during a survey, White and Garrott 1990) was determined from radio telemetry observations and/or weekly survey data.

Data Analysis

Three estimates describing the Key deer population were obtained from survey data: (1) population density, (2) female:male sex ratios, and (3) fawn:doe ratios. Population size for Big Pine and No Name keys was determined from the BPK44m and NNK survey data using Chapman's modification of the Lincoln-Petersen estimator (White et al. 1982)

$$N = \left(\frac{(n+1)(M+1)}{(m+1)} \right) - 1$$

where N was equal to the population size, n was equal to the number of marked and unmarked deer seen on a survey, and m was equal to the number of marked deer seen on a survey. The BPK44m and NNK routes met the requirements for this estimator because (1) each survey adequately covered what was a closed population (both areas are islands), and (2) a subset of each population was marked when surveys were conducted. For these weekly surveys, the number of marked and unmarked deer observed were recorded, and a population estimate was

generated. Sex and fawn:doe ratio estimates were determined for each survey from all 5 survey routes. Only surveys with $\geq$ 10 deer observations were used in determining density estimates, and sex and fawn:doe ratio estimates.

For density estimates, differences in period (historic vs. present study), year, time of day (sunrise, sunset), and season were tested. Seasons were defined as winter (January-March, pre-fawning1 season), spring (April-June, fawning season), summer (July-September, pre-breeding season), and fall (October-December, breeding season, Silvy 1975). In comparing sex and fawn:doe ratio estimates, differences by survey type, time of day, and season were compared. For all comparisons, an ANOVA was used to test for differences, and Tukey's HSD for multiple comparisons was used to separate means when *F*-values were significant ($P < 0.05$, Ott 1993).

RESULTS

A total of 1,384 surveys was conducted (Table 4.2). The majority (1,044/1,384, 75%) of surveys occurred during the 2 research projects, with the remaining surveys occurring between the 2 studies.

Density Estimates

In the historic study, Silvy (1975) estimated deer on Big Pine and No Name numbered 167 and 34, respectively (201 total). Currently, the number of deer on Big Pine and No Name is estimated to be approximately 406 and 76, respectively (482 total). These estimates suggest the Key deer population on these 2 islands has increased by 240% (Fig. 4.2).

In comparing density estimates for Big Pine, period, time of day, and season were found to be significant ($P < 0.034$) in predicting deer density (Table 4.3). Differences observed between the historic and present study, as previously mentioned, included a 240% increase in the deer population. In comparing estimates within each study, however, no year effect or difference between years was found (Table 4.4). Data suggest the time of day that a survey was conducted was an important predictor of deer density. For the historic study, the sunrise survey gave lower estimates as compared to the present study, where sunset survey estimates were lower (Tables 4.3-4.4). For the NNK survey, estimates from night surveys were lower than both sunset and sunrise surveys (Table 4.3).

Sex Ratios

Survey data suggest the deer population structure on both Big Pine and No Name were female-bias, particularly on Big Pine Key (Table 4.5, Figs. 4.3-4.4). In testing for differences in female:male ratios, route type and season were found to be significant ($P < 0.001$), but no differences ($P = 0.259$) in estimates between time of day were observed. In general, sex ratio estimates from the USFWS survey were higher than other survey types, but sex ratio estimates between the historic and present study were similar (Figs. 4.3-4.4). Female:male ratios were found to be higher for the BPK10m survey as compared to the BPK44m survey, suggesting that a greater number of females reside in the northern end of Big Pine Key (Table 4.5, Fig. 4.3). Lastly, estimates between seasons were similar except for USFWS surveys where ratios were greatest during the winter and spring, and gradually decreased during the summer and fall (Figs. 4.3-4.4).

Fawn:Doe Ratios

Survey data suggest that average fawn:doe ratio estimates observed varied by season, survey type, and time of day. In general, fawn:doe estimates were lowest in spring and summer and increased in fall and winter (Table 4.6, Figs. 4.5-4.6). Fawn:doe ratios also were higher for the BPK10m survey as compared to the BPK44m, NNK, and USFWS surveys. Lastly, fawn:doe ratios were lower during the night survey as compared to the sunrise and sunset (Table 4.6). In combining estimates from the BPK44m, NNK, FWS fall, and USFWS surveys by season, the highest average fawn:doe ratio observed (0.39 fawn:doe) was during the fall season (October-November).

Table 4.2. Number of surveys conducted by season and route type for Big Pine and No Name keys, 1969-01.

Time	Fall	Spring	Summer	Winter	Total
BPK10m					
Night	39	49	41	49	178
Sunrise	31	34	27	29	121
Sunset	30	34	27	31	122
Total	100	117	95	109	421
BPK44m					
Sunrise	37	40	34	38	149
Sunset	38	40	34	40	152
Total	75	80	68	78	301
FWS Fall					
Night	67	0	7	0	74
Total	67	0	7	0	74
NNK					
Night	20	17	16	21	74
Sunrise	30	34	27	31	122
Sunset	32	35	27	32	126
Total	82	86	70	84	322
USFWS					
Night	64	70	67	65	266
Total	64	70	67	65	266
Grand Total	388	353	307	336	1,384

Table 4.3. Key deer density estimates for Big Pine and No Name keys, 1969-72 and 1998-01.

Survey						Tests[a]		
Period	Time	Season	*n*	$\hat{\theta}$	SE	Period	Time	Season
BPK44m								
Historic	Sunrise	Fall	6	132	24	A	A	AB
Historic	Sunrise	Spring	6	144	13	A	A	AB
Historic	Sunrise	Summer	7	110	11	A	A	A
Historic	Sunrise	Winter	7	176	15	A	A	B
Historic	Sunset	Fall	6	172	20	A	B	AB
Historic	Sunset	Spring	6	203	34	A	B	AB
Historic	Sunset	Summer	7	178	27	A	B	A
Historic	Sunset	Winter	9	209	31	A	B	B
Present	Sunrise	Fall	31	415	42	B	A	AB
Present	Sunrise	Spring	34	457	51	B	A	AB
Present	Sunrise	Summer	27	562	52	B	A	A
Present	Sunrise	Winter	31	376	24	B	A	B
Present	Sunset	Fall	32	370	25	B	B	AB
Present	Sunset	Spring	34	340	19	B	B	AB
Present	Sunset	Summer	27	412	30	B	B	A
Present	Sunset	Winter	31	338	45	B	B	B
Historic	Sunrise	Combined	26	141	9			
Historic	Sunset	Combined	28	192	14			
Historic	Combined	Combined	54	167	9			
Present	Sunrise	Combined	123	449	23			
Present	Sunset	Combined	124	363	16			
Present	Combined	Combined	247	406	14			
$F_{1,2}$						65.28	7.20	2.93
P						0.000	0.008	0.034

Table 4.3. Continued.

Survey						Tests[a]		
Period	Time	Season	*n*	0	SE	Period	Time	Season
NNK								
Present	Night	Fall	20	52	8		A	A
Present	Night	Spring	17	73	11		A	A
Present	Night	Summer	16	61	8		A	A
Present	Night	Winter	21	77	7		A	A
Present	Sunrise	Fall	30	81	7		B	A
Present	Sunrise	Spring	34	82	7		B	A
Present	Sunrise	Summer	27	108	12		B	A
Present	Sunrise	Winter	32	71	5		B	A
Present	Sunset	Fall	32	86	9		AB	A
Present	Sunset	Spring	35	68	5		AB	A
Present	Sunset	Summer	27	81	5		AB	A
Present	Sunset	Winter	32	65	5		AB	A
Present	Night	Combined	74	66	4			
Present	Sunrise	Combined	122	85	4			
Present	Sunset	Combined	126	75	3			
Present	Combined	Combined	322	76	2			
$F_{2,3}$							5.43	2.18
P							0.005	0.091

[a]*F* and *P* values are for overall comparisons.

Table 4.4. Key deer annual density estimates for Big Pine and No Name keys, 1969-72 and 1998-01.

Survey					Tests[a]	
Year	Time	*n*	$\hat{\theta}$	SE	Year	Time
BPK44m						
1971	Sunrise	26	141	9	A	A
1971	Sunset	27	194	15	A	B
1972	Sunset	1	126	--	A	B
1998	Sunrise	36	447	43	B	A
1998	Sunset	36	366	22	B	B
1999	Sunrise	48	400	25	B	A
1999	Sunset	48	332	22	B	B
2000	Sunrise	32	498	42	B	A
2000	Sunset	33	408	40	B	B
2001	Sunrise	7	571	210	B	A
2001	Sunset	7	342	67	B	B
1971	Combined	53	168	9		
1972	Combined	1	126	--		
1998	Combined	72	407	24		
1999	Combined	96	366	17		
2000	Combined	65	452	29		
2001	Combined	14	457	110		
$F_{1,5}$					14.59	7.33
P					0.000	0.007
NNK						
1998	Sunrise	36	105	6	A	A
1998	Sunset	36	81	4	AB	A
1999	Night	43	63	5	B	AB
1999	Sunrise	48	82	7	A	AB
1999	Sunset	48	74	7	AB	AB

Table 4.4. Continued.

Survey					Tests[a]	
Year	Time	*n*	0	SE	Year	Time
2000	Night	29	72	7	B	B
2000	Sunrise	31	63	5	A	B
2000	Sunset	34	69	5	AB	B
2001	Night	2	46	4	B	AB
2001	Sunrise	7	97	24	A	AB
2001	Sunset	8	77	12	AB	AB
1998	Combined	72	93	4		
1999	Combined	139	73	4		
2000	Combined	94	68	3		
2001	Combined	17	82	12		
$F_{2,3}$					4.35	3.04
P					0.005	0.049

[a]*F* and *P* values are for overall comparisons.

Table 4.5. Key deer average sex ratios (female:male) by survey route for Big Pine and No Name keys, 1969-01.

						Tests[a]		
Route	Season	Time	*n*	θ	SE	Route	Season	Time
BPK10m	Fall	Night	9	2.29	0.20	A	A	A
BPK10m	Fall	Sunrise	9	3.03	0.32	A	A	A
BPK10m	Fall	Sunset	9	2.46	0.37	A	A	A
BPK10m	Spring	Night	12	2.32	0.13	A	B	A
BPK10m	Spring	Sunrise	10	4.62	0.30	A	B	A
BPK10m	Spring	Sunset	10	2.96	0.25	A	B	A
BPK10m	Summer	Night	10	2.14	0.38	A	A	A
BPK10m	Summer	Sunrise	8	3.31	0.58	A	A	A
BPK10m	Summer	Sunset	8	2.48	0.25	A	A	A
BPK10m	Winter	Night	11	2.84	0.35	A	B	A
BPK10m	Winter	Sunrise	7	4.75	0.63	A	B	A
BPK10m	Winter	Sunset	7	2.39	0.25	A	B	A
BPK44m	Fall	Sunrise	12	2.07	0.19	AB	A	A
BPK44m	Fall	Sunset	12	2.25	0.23	AB	A	A
BPK44m	Spring	Sunrise	13	1.79	0.18	AB	B	A
BPK44m	Spring	Sunset	13	2.47	0.20	AB	B	A
BPK44m	Summer	Sunrise	11	1.76	0.08	AB	A	A
BPK44m	Summer	Sunset	11	2.63	0.22	AB	A	A
BPK44m	Winter	Sunrise	11	2.34	0.34	AB	B	A
BPK44m	Winter	Sunset	12	2.42	0.22	AB	B	A
FWS Fall	Fall	Night	11	3.24	0.31	AC	A	A
FWS Fall	Summer	Night	1	4.84	--	AC	A	A
NNK	Fall	Night	6	1.02	0.21	B	A	A
NNK	Fall	Sunrise	9	1.97	0.41	B	A	A
NNK	Fall	Sunset	9	1.56	0.20	B	A	A
NNK	Spring	Night	6	1.54	0.39	B	B	A
NNK	Spring	Sunrise	10	1.88	0.31	B	B	A

Table 4.5. Continued.

						Tests[a]		
Route	Season	Time	*n*	0	SE	Route	Season	Time
NNK	Spring	Sunset	10	1.31	0.14	B	B	A
NNK	Summer	Night	5	1.19	0.22	B	A	A
NNK	Summer	Sunrise	8	1.60	0.25	B	A	A
NNK	Summer	Sunset	8	1.40	0.19	B	A	A
NNK	Winter	Night	6	1.32	0.13	B	B	A
NNK	Winter	Sunrise	8	1.92	0.17	B	B	A
NNK	Winter	Sunset	8	1.72	0.15	B	B	A
USFWS	Fall	Night	62	4.06	0.33	C	A	A
USFWS	Spring	Night	69	7.06	0.72	C	B	A
USFWS	Summer	Night	62	3.68	0.24	C	A	A
USFWS	Winter	Night	65	6.62	0.71	C	B	A
BPK10m	Fall	Combined	27	2.59	0.18			
BPK10m	Spring	Combined	32	3.24	0.22			
BPK10m	Summer	Combined	26	2.60	0.25			
BPK10m	Winter	Combined	25	3.25	0.30			
BPK44m	Fall	Combined	24	2.16	0.15			
BPK44m	Spring	Combined	26	2.13	0.15			
BPK44m	Summer	Combined	22	2.19	0.15			
BPK44m	Winter	Combined	23	2.38	0.19			
FWS Fall	Fall	Combined	11	3.24	0.31			
FWS Fall	Summer	Combined	1	4.84	--			
NNK	Fall	Combined	24	1.58	0.19			
NNK	Spring	Combined	26	1.58	0.16			
NNK	Summer	Combined	21	1.42	0.13			
NNK	Winter	Combined	22	1.69	0.10			
USFWS	Fall	Combined	62	4.06	0.33			
USFWS	Spring	Combined	69	7.06	0.72			
USFWS	Summer	Combined	62	3.68	0.24			
USFWS	Winter	Combined	65	6.62	0.71			

Table 4.5. Continued.

						Tests[a]		
Route	Season	Time	*n*	0	SE	Route	Season	Time
BPK10m	Combined	Combined	110	2.93	0.12			
BPK44m	Combined	Combined	95	2.21	0.08			
FWS Fall	Combined	Combined	12	3.37	0.31			
NNK	Combined	Combined	93	1.57	0.07			
USFWS	Combined	Combined	258	5.42	0.30			
$F_{2,5}$						17.83	10.98	1.36
P						0.000	0.000	0.259

[a]*F* and *P* values are for overall comparisons.

Table 4.6. Key deer average fawn:doe ratios by survey route for Big Pine and No Name keys, 1969-01.

						Tests[a]		
Route	Season	Time	*n*	θ	SE	Route	Season	Time
BPK10m	Fall	Night	9	0.76	0.07	A	A	A
BPK10m	Fall	Sunrise	9	0.48	0.10	A	A	B
BPK10m	Fall	Sunset	9	0.47	0.06	A	A	B
BPK10m	Spring	Night	12	0.17	0.02	A	B	A
BPK10m	Spring	Sunrise	10	0.06	0.01	A	B	B
BPK10m	Spring	Sunset	10	0.10	0.01	A	B	B
BPK10m	Summer	Night	10	0.37	0.08	A	C	A
BPK10m	Summer	Sunrise	8	0.33	0.06	A	C	B
BPK10m	Summer	Sunset	8	0.34	0.05	A	C	B
BPK10m	Winter	Night	11	0.78	0.10	A	A	A
BPK10m	Winter	Sunrise	7	0.49	0.04	A	A	B
BPK10m	Winter	Sunset	7	0.57	0.05	A	A	B
BPK44m	Fall	Sunrise	12	0.44	0.05	A	A	B
BPK44m	Fall	Sunset	12	0.51	0.06	A	A	B
BPK44m	Spring	Sunrise	13	0.06	0.01	A	B	B
BPK44m	Spring	Sunset	13	0.05	0.01	A	B	B
BPK44m	Summer	Sunrise	11	0.28	0.04	A	C	B
BPK44m	Summer	Sunset	11	0.28	0.03	A	C	B
BPK44m	Winter	Sunrise	11	0.43	0.05	A	A	B
BPK44m	Winter	Sunset	12	0.49	0.06	A	A	B
FWS Fall	Fall	Night	11	0.32	0.02	B	A	A
FWS Fall	Summer	Night	1	0.09	--	B	C	A
NNK	Fall	Night	6	0.87	0.17	A	A	A
NNK	Fall	Sunrise	9	0.35	0.08	A	A	B
NNK	Fall	Sunset	9	0.41	0.04	A	A	B
NNK	Spring	Night	6	0.30	0.07	A	B	A
NNK	Spring	Sunrise	10	0.14	0.02	A	B	B

Table 4.6. Continued.

						Tests[a]		
Route	Season	Time	*n*	θ	SE	Route	Season	Time
NNK	Spring	Sunset	10	0.17	0.05	A	B	B
NNK	Summer	Night	5	0.34	0.05	A	C	A
NNK	Summer	Sunrise	8	0.24	0.04	A	C	B
NNK	Summer	Sunset	8	0.27	0.07	A	C	B
NNK	Winter	Night	6	0.33	0.06	A	A	A
NNK	Winter	Sunrise	8	0.32	0.06	A	A	B
NNK	Winter	Sunset	8	0.31	0.05	A	A	B
USFWS	Fall	Night	62	0.23	0.02	B	A	A
USFWS	Spring	Night	69	0.08	0.01	B	B	A
USFWS	Summer	Night	62	0.17	0.01	B	C	A
USFWS	Winter	Night	65	0.18	0.02	B	A	A
BPK10m	Fall	Combined	27	0.57	0.05			
BPK10m	Spring	Combined	32	0.12	0.01			
BPK10m	Summer	Combined	26	0.35	0.04			
BPK10m	Winter	Combined	25	0.64	0.05			
BPK44m	Fall	Combined	24	0.48	0.04			
BPK44m	Spring	Combined	26	0.06	0.01			
BPK44m	Summer	Combined	22	0.28	0.02			
BPK44m	Winter	Combined	23	0.46	0.04			
FWS Fall	Fall	Combined	11	0.32	0.02			
FWS Fall	Summer	Combined	1	0.09	--			
NNK	Fall	Combined	24	0.50	0.07			
NNK	Spring	Combined	26	0.19	0.03			
NNK	Summer	Combined	21	0.27	0.03			
NNK	Winter	Combined	22	0.32	0.03			
USFWS	Fall	Combined	62	0.23	0.02			
USFWS	Spring	Combined	69	0.08	0.01			
USFWS	Summer	Combined	62	0.17	0.01			
USFWS	Winter	Combined	65	0.18	0.02			

Table 4.6. Continued.

						Tests[a]		
Route	Season	Time	*n*	θ	SE	Route	Season	Time
BPK10m	Combined	Combined	110	0.40	0.03			
BPK44m	Combined	Combined	95	0.31	0.02			
FWS Fall	Combined	Combined	12	0.30	0.03			
NNK	Combined	Combined	93	0.32	0.02			
USFWS	Combined	Combined	258	0.16	0.01			
$F_{2,5}$						49.51	77.98	23.11
P						0.000	0.000	0.000

[a]*F* and *P* values are for overall comparisons.

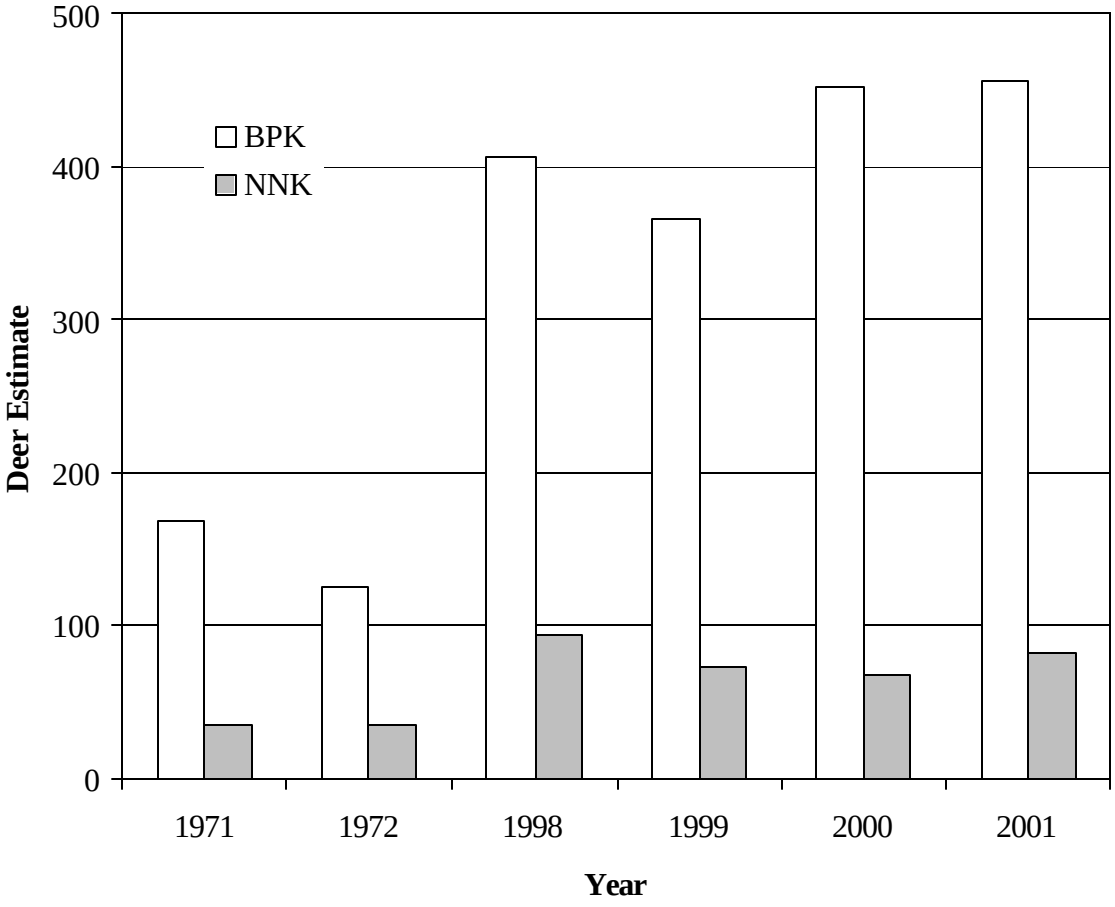


Fig. 4.2. Annual deer estimates for Big Pine and No Name keys, 1971-72 and 1998-01.

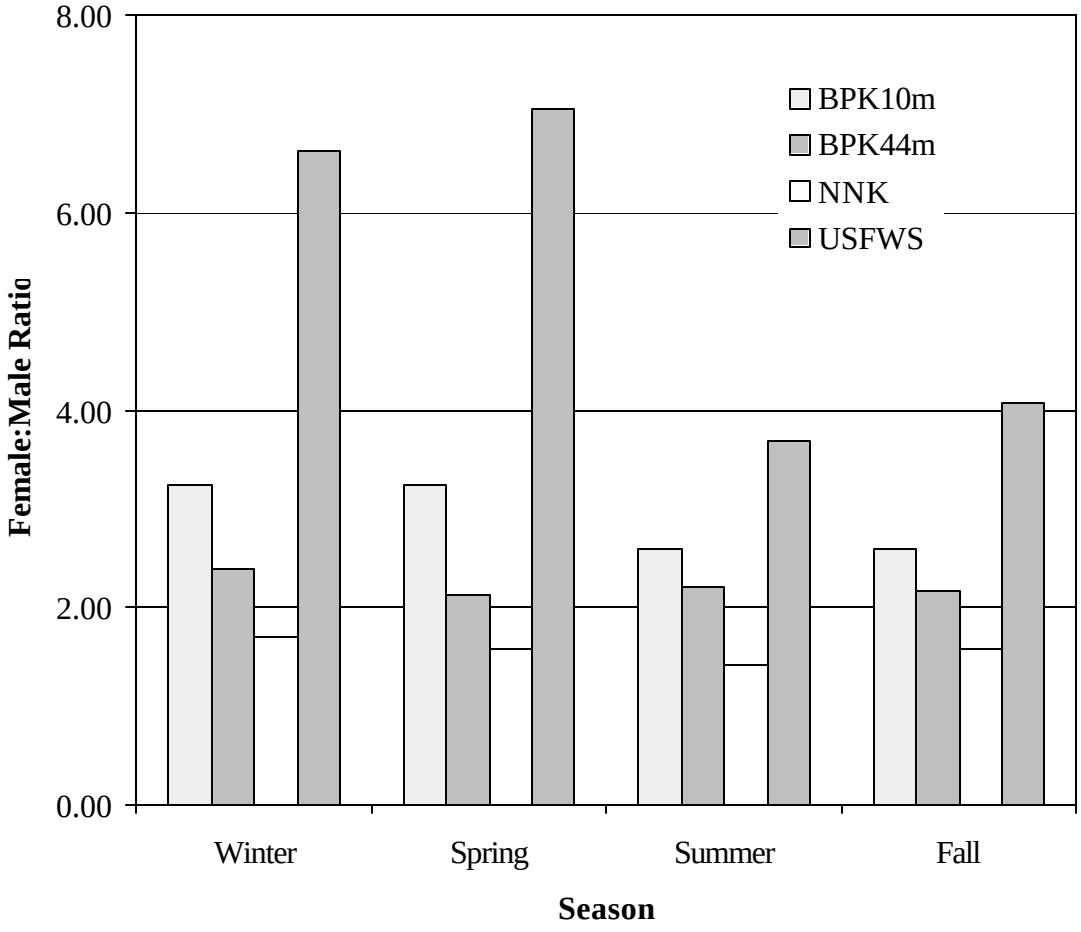


Fig. 4.3. Average female:male ratio estimates by survey route and season for Big Pine and No Name keys, 1971-01.

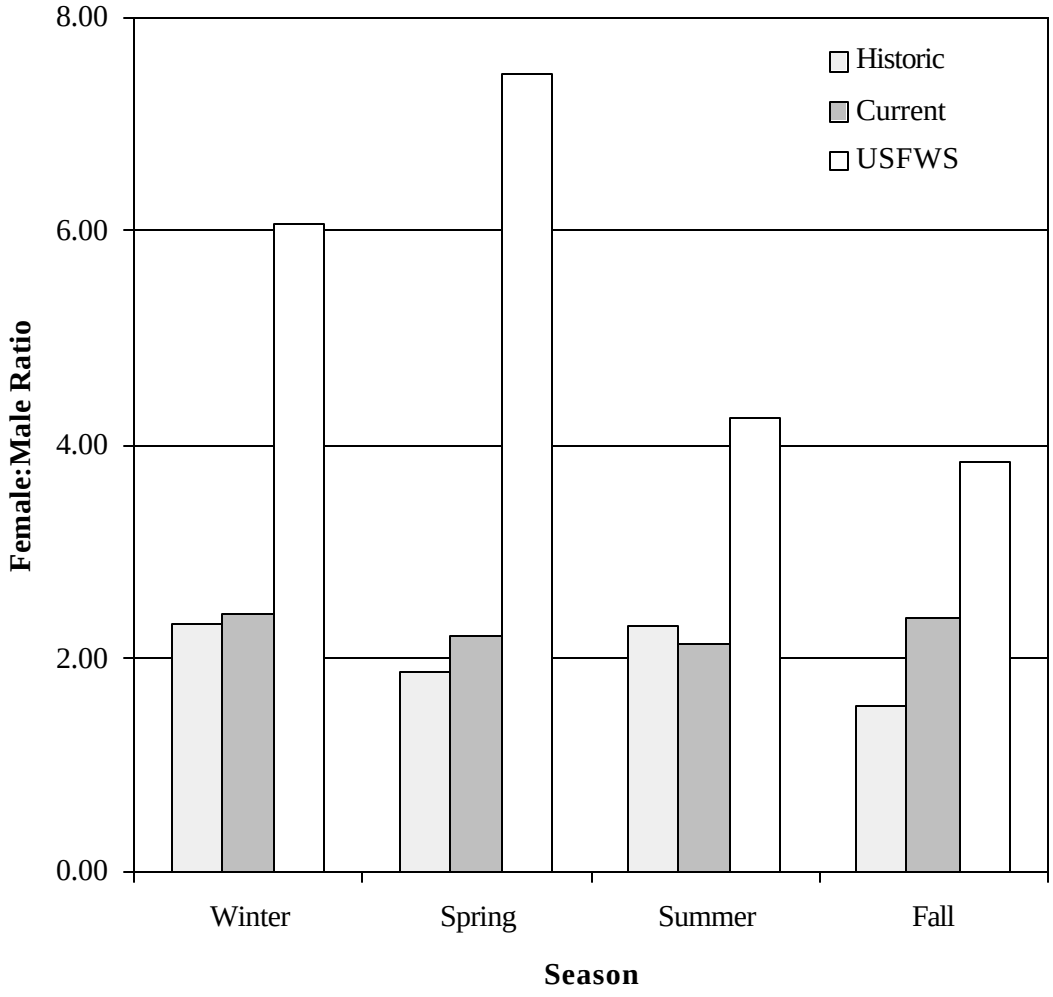


Fig. 4.4. Average female:male ratio estimates for the Big Pine 44-mile route by period (Historic – 1971-72, Current – 1998-01, USFWS – 1985-95).

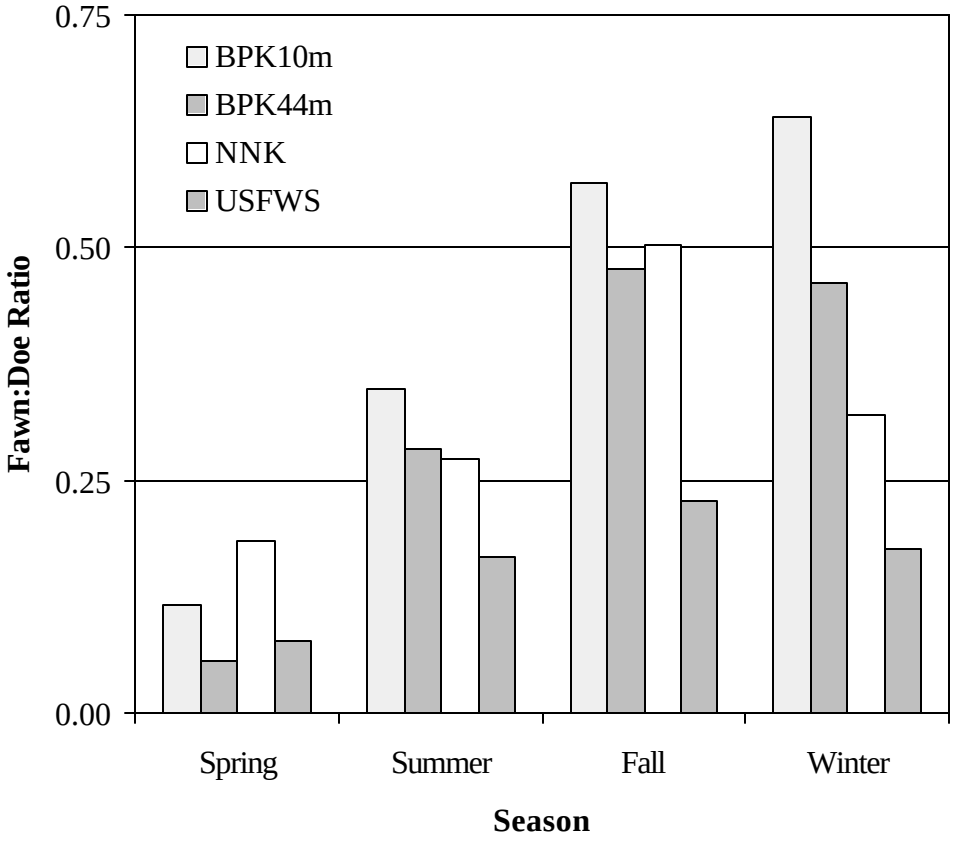


Fig. 4.5. Average fawn:doe ratio estimates by survey route and season for Big Pine and No Name keys, 1971-01.

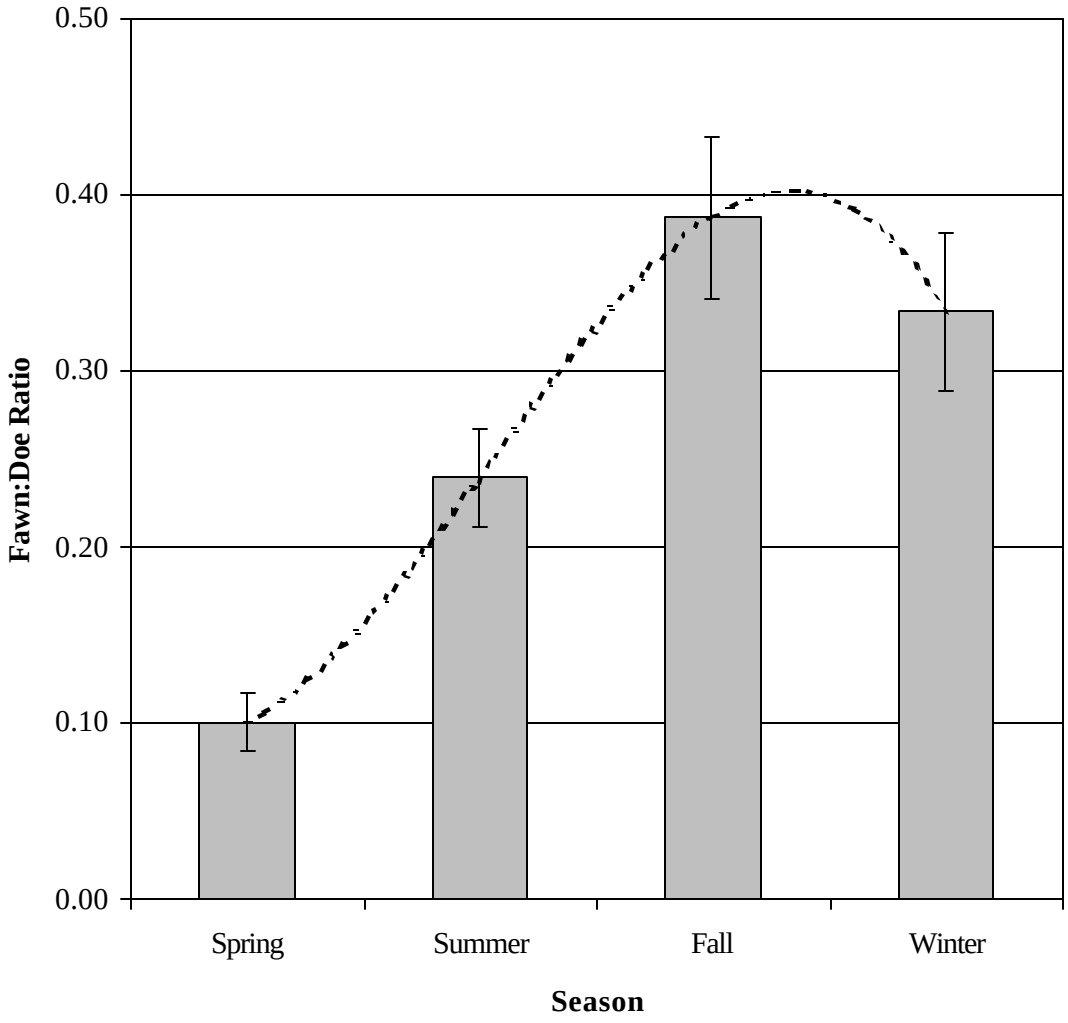


Fig. 4.6. Average fawn:doe estimates by season for Big Pine and No Name keys, 1971-01.

DISCUSSION

Density Estimates

The Key deer population on Big Pine and No Name has increased by approximately 240% since 1972. Collectively, 450-515 deer occupy Big Pine and No Name keys, the highest recorded estimate for these 2 islands. The increase in overall deer numbers is due to the protection of Key deer from illegal hunting through law enforcement efforts and the favorable response of the deer population to urban development.

Urban development in the Keys is typically viewed as threatening the recovery and management of Key deer (Klimstra et al. 1974, Folk 1991). Urban development, however, appears to have benefited the deer population through the conversion of marginal habitat such as mangrove and buttonwood forests. For example, it is proposed that dredge and fill operations, which began in the mid-1940's and continued to the mid-1970's, actually resulted in the creation of "uplands", providing Key deer with both native and ornamental vegetation that could not be supported previously in these areas (Chapter III, Gallagher 1991). Thus, urban development in the form of land clearing increased the overall "carrying capacity" (defined as the maximum number of animals an environment will support on a sustained basis without destruction of the vegetation, Caughley 1977) on these 2 islands. Similar increases in other white-tailed deer populations also have been observed in other parts of the United States (McShea et al. 1997). Continued development in the form of houses and/or businesses, however, might not provide the same benefit as increases in secondary impacts (i.e., road mortality, habitat loss, entanglement) would be expected (Chapters II-III).

In reviewing survey data, time of day was found to be an important factor in predicting density estimates. Data suggests that historic estimates were higher for sunrise surveys, whereas estimates from the current study were higher for sunset surveys. Differences in population estimates might be explained by differences in trapping protocol between the 2 studies. For example, in the historic study, the majority of deer were trapped at night. In the current study on the other hand, the majority of deer were trapped in early morning hours (Chapter II). As a result, observation probabilities might differ by time of day due to trapping effects that would result in slightly different density estimates (White et al. 1982). Such differences should be taken into account in estimating deer densities in the future.

Sex Ratios

Survey data suggest the Key deer population is female-biased, particularly on Big Pine Key. The high female-male sex ratio observed is attributed to (1) observer bias, particularly from USFWS counts, and (2) differential survival observed between sexes (Chapter II).

Female:male ratios from USFWS counts were found to be significantly higher than other survey methods, which might be explained by the misclassification of sexes due to inexperienced observers and/or the difficulty in sexing animals at night. This difference is illustrated when comparing sex ratios between seasons by survey route. Higher sex ratios were observed in winter and spring for the USFWS counts when male Key deer are antlerless (Fig. 4.3, Hardin 1974). Furthermore, it is proposed that sexing individuals at night might also be more difficult than sexing individuals during sunrise or sunset hours. USFWS biologists should take into account these potential biases and might consider the use of sunrise or sunset surveys in the future to reduce misclassifications. For example, no differences in sex ratios was found between the historic and present study on the BPK44m route (Fig. 4.4), and this might be attributed to an increase in observer precision because of better light conditions. Using data from only the historic and present BPK44m, the average female:male ratio is estimated to be approximately 2.21:1 for Big Pine Key.

Previous studies (Klimstra et al. 1974, Hardin 1974, Folk and Klimstra 1991a) reported that Key deer fetal sex ratios are male biased (57-74% males). Poor nutrition of does often times is cited as the reason for male-bias in fetal sex ratios from the theoretical 1:1 ratio (Verme 1983, Caley and Nudds 1987, Folk and Klimstra 1991a). It is hypothesized that female condition is directly related to range condition, thus, poor range conditions would result in a greater number of males being born due to the smaller reproductive cost (Caley and Nudds 1987). Despite the male-bias fetal sex ratio reported for the Key deer population, the overall population sex ratio for Big Pine was female-bias (approximately 2:1), contrary to what would be expected. It is hypothesized the female-bias observed is due to differential survival (females have a greater survival than males), that would eventually favor a female-bias population sex ratio (Chapter II). In comparing the BPK10m to the BPK44m, a higher female:male ratio was observed for the BPK10m survey (3:1 versus 2:1). This suggests that a higher number of females reside in the northern half of Big Pine Key, whereas the southern half is closer to a 1:1 ratio. The greater number of females in north Big Pine Key might be explained by female fidelity to traditional breeding sites. For example, previous studies

(Rosenberry et al. 1999, Nelson and Mech 1999, Rosenberry et al. 2001) reported that male deer tend to disperse from their natal sites but female dispersal is limited or non-existent. Similar results in comparing ranges and dispersal between sexes were found in the study of Key deer (Chapter V).

Fawn:Doe Ratios

In comparing fawn:doe ratio estimates by season, the highest average fawn:doe ratio observed, approximately 0.39 fawns per doe, was in early fall (October). In general, fawn:doe estimates were lowest in spring and summer, and gradually increased in the fall and winter (Figs. 4.5-4.6). This is not surprising considering the peak fawning period for Key deer is 1 April, and previous studies have reported that Key deer fawns are stationary until about 4-6 months of age (Hardin 1974). As a result, fawns born in the spring and summer are not seen along survey routes until several months later. The continued use of FWS fall counts, which occur in the first week of October, is recommended to index fawn production in the deer population.

In comparing fawn:doe ratios between survey types, the highest fawn:doe ratios observed were for the BPK10m counts followed by the BPK44m counts. As previously mentioned, higher female:male ratios were observed from the BPK10m survey. Higher fawn:doe ratios from BPK10m counts is not suprising due to the greater number of females that occupy that area. Collectively, higher female:male ratios and higher fawn:doe ratios in north Big Pine Key suggests the majority of breeding and fawning occurs in this area. Fortunately, the majority of property in this area is owned and managed by the NKDR (Chapter I).

Management Implications

Herd health indices and vegetation surveys suggest the Key deer population is at or near carrying capacity, particularly on No Name Key (Nettles et al. 2001, M. Barrett, University of South Florida, unpublished data). For example, abomasal parasite counts (APC) are often times used as an index to carrying-capacity for white-tailed deer (Davidson and Doster 1996). In general, white-tailed deer populations with > 1,000 APC are believed to be at or above carrying-capacity, which is the case for the Key deer (Nettles et al. 2001).

Assuming deer on No Name are at carrying-capacity, the deer density for this island is estimated at 0.17 deer/ha (76 deer/459 ha). Using the deer density from No Name as a baseline, estimates for Big Pine Key would be approximately 6% below carrying capacity with

an estimate of 0.16 deer/ha (406 deer/2,533 ha). Study results found highway mortality is highest on Big Pine Key, especially in the southern portion of the island (Chapter II). It is suggested that highway mortality might be responsible for the deer population being below carrying capacity on Big Pine Key. Future efforts to reduce road mortality should take this into account in the management of the deer population. A reduction in road mortality would likely result in an increase in the deer population, that would require biologists to consider other means of population control. Furthermore, with high population numbers being observed other management strategies such as deer translocations might be considered. Deer could be translocated to islands with deer numbers substantially below carrying capacity. This would have the added benefit of spreading risk and improving the long-term viability of the species (Chapters VII-VIII).

Population surveys are an important part in the management and recovery of the endangered Key deer. In the future, the continuing use of the USFWS monthly surveys is recommended due to the long-term period in which these data have been collected (+25 years). Unfortunately, it is suggested that these data are rather limited in comparison to short, intense surveys such as the FWS fall counts (Rakestraw et al. 1998). Continuation of the FWS fall counts is encouraged in addition to the implementation of spring counts in April. Spring counts (first week of April) identical to the USFWS or FWS fall route would provide biologists with additional insight into fawn survival between 6-12 months. Furthermore, it is recommended that future surveys should begin at 1.5 hours prior to sunset to increase the number of deer observed and avoid the misclassification of deer.

CHAPTER V

RANGES AND DISPERSAL PATTERNS

SYNOPSIS

The sociobiology of Key deer appears to have changed in recent years as a result of increasing contact with humans. It is hypothesized that a reduction in ranges and daily movements has occurred in the last several years due to the taming of deer. These changes in Key deer ranges and movements, however, have not been evaluated. The study objectives were to (1) evaluate changes in seasonal and annual ranges and core areas, (2) evaluate changes in seasonal and annual daily movements, and, (3) determine dispersal rates (1998-00) by sex between Big Pine and No Name keys. Key deer were radio-collared as part of 2 separate research projects conducted December 1968-June 1972, and January 1998-December 2000. A total of 96 (females, n = 62; males, n = 34) and 163 (females, n = 62; males, n = 34) radio-collared Key deer was used to calculate annual and seasonal movements, respectively. In general, season and age were not found to be important factors in describing the ranges and movements of Key deer, while sex and period (historic and present study) were important. On average, male annual ranges (Θ = 221-388 ha) were greater than female annual ranges (Θ = 42-101 ha), which might explain higher male mortality observed due to road mortality. In comparing ranges and daily movements between the historic and current study, historic ranges (Θ = 101-388 ha) were greater than present ranges (Θ = 42-221 ha). It is proposed that changes in population density and the taming of deer collectively have resulted in a decrease in ranges and movements for this endangered deer herd. Male dispersal (11%) was found to be greater than female dispersal (3%). It is hypothesized that younger animals, particularly males, which have been shown to readily disperse from natal sites are primarily responsible for recolonization after local extinction. This suggests that future management strategies such as deer translocations might consider the sex and age of target animals to ensure overall success.

INTRODUCTION

Urban development in the Keys has been a concern in the recovery and management of the Key deer for the last several years (Klimstra et al. 1974, Folk 1991). The sociobiology of Key deer appears to have changed in recent years as a result of increasing contact with humans

(Folk 1991, Folk and Klimstra 1991b). It is hypothesized that a reduction in ranges and daily movements has occurred in the last several years due to the taming of deer (Folk and Klimstra 1991b). Changes in Key deer ranges and movements, however, have not been evaluated.

Dispersal is an important mechanism in the persistence of a metapopulation (Akcakaya 2000), and, it is assumed that dispersal decreases the extinction risk by the recolonization of local populations that go extinct (Akcakaya 1991). The level of dispersal that occurs between islands is currently unknown. A PVA is currently being conducted as part of an HCP for Big Pine and No Name keys (Chapters I and VII). Key deer dispersal between islands had been noted in previous studies (Hardin 1974, Silvy 1975), however, reliable estimates of dispersal between Big Pine and No Name keys that can be used in a PVA are lacking.

The study objective was to gain an understanding of the ranges and dispersal patterns of this endangered deer herd. Key deer were radio-collared as part of 2 separate field studies (1968-72 and 1998-00). These data were used to address several study objectives: (1) evaluate changes in seasonal and annual ranges and core areas, (2) evaluate changes in seasonal and annual daily movements, and (3) determine dispersal rates (1998-00) by sex between Big Pine and No Name keys. Terms used in this study to describe deer movements were defined as follows: (1) ranges – 95% probability area determined from radio locations, (2) core areas – 50% probability area determined from radio locations, (3) daily movements – Euclidean distances between daily radio locations, and (4) dispersal – emigration and immigration of individuals between islands (White and Garrott 1990, Hooge and Eichenlaub 1999, Akcakaya 2000).

METHODS

Radio Telemetry

Key deer were radio-collared as part of 2 research projects conducted December 1968-June 1972, and January 1998-December 2000 on Big Pine and No Name keys. All telemetry data described in this chapter were collected on these 2 islands (Chapter I). Deer were captured during the length of both studies using portable drive nets, drop nets, and hand capture (Silvy 1975, Silvy et al. 1975, Lopez et al. 1998). Key deer were classified by sex and age at time of capture. Age categories included fawns (assumed all deer were born on 1 April), yearlings (1-2 years old), or adults (> 2 years old) based on tooth wear and replacement (Severinghaus 1949). Captured deer were marked using plastic neck collars (8-cm wide, primarily females of all age-

classes), leather antler collars (0.25-cm wide, yearling and adult males only), or elastic expandable neck collars (3-cm wide, primarily male fawns/yearlings). A battery-powered mortality-sensitive radio transmitter (150-152 MHz, 100-110 g for plastic neck collars, 10-20 g for antler transmitters and elastic collars, Advanced Telemetry Systems, Isanti, Minnesota, USA) was attached to collar material. In addition, each captured animal received an ear tattoo, which served as a permanent marker (Silvy 1975).

Radio-collared deer were monitored 6-7 times per week at random intervals (24-hour period was divided into 6 equal 4-hour segments; one 4-hour segment was randomly selected and all deer were located during that time, Silvy 1975). Deer locations were determined via homing and triangulation (Silvy 1975, White and Garrott 1990). Telemetry locations were entered into a GIS using ArcView (Version 3.2) and Microsoft Access (Version 97).

Data Analysis

Key deer ranges (95% probability area) and core areas (50% probability area) were calculated using a fixed-kernel home-range estimator (Worton 1989, Seaman et al. 1998, Seaman et al. 1999) with the animal movement extension in ArcView (Hooge and Eichenlaub 1999). Calculation of the smoothing parameter (kernel width) as described by Silverman (1986) was used in generating kernel range estimates.

Seasonal ranges (ha), core areas (ha), and mean daily movements (m) were calculated by season, sex, age, and period (historic study, present study). Seasons were defined as winter (January-March, pre-fawning season), spring (April-June, fawning season), summer (July-September, pre-breeding season), and fall (October-December, breeding season, Silvy 1975). Only deer with $\geq$ 50 locations were used to calculate movement estimates, as recommended by Seaman et al. (1999). Annual ranges (ha), core areas (ha), and mean daily movements (m) were calculated by year, sex, age, and period (historic study, present study). Only deer with $\geq$ 175 locations were used to calculate annual estimates (Seaman et al. 1999). Differences in ranges, core areas, and mean daily movements were tested using an ANOVA, followed by Tukey's HSD for multiple comparisons to separate means when *F*-values were significant ($P \leq 0.05$, Ott 1993).

The Key deer PVA model consisted of a demographic and spatially-structured model (Chapter VII, Akcakaya 2000). In the model, it was assumed that all reproduction occurred in a relatively short breeding season (1 April, Hardin 1974, "birth-pulse" population) and that local populations were surveyed after each breeding season (post-reproductive survey, Chapter VII, Akcakaya 1991, Caswell 2000). As a result of these assumptions, an estimate of dispersal (defined as the permanent movement of deer (%) from one island to another) during the month of April was necessary. Dispersal was estimated for each sex by dividing the number of deer dispersing during April by the total sample size (Akcakaya and Attwood 1997). Dispersal rates by sex, year, and, direction (e.g., Big Pine to No Name, No Name to Big Pine) were determined and averaged.

RESULTS

A total of 96 (females, n = 62; males, n = 34) and 163 (females, n = 62; males, n = 34) radio-collared Key deer was used to calculate annual and seasonal movements, respectively (Table 5.1). The average number of locations used to calculate seasonal ranges, core areas, and mean daily movements was 76 (SD = 14, range = 50-124), while the average number of locations used to calculate annual ranges, core areas, and mean daily movements was 242 (SD 42, range = 175-380). Total number of radio locations used in the analyses was 40,248.

Seasonal Movements

Results suggest that sex and period were significant ($P < 0.001$) while season and age were not important ($P = 0.056$-0.362) in describing Key deer seasonal ranges and core areas (Tables 5.2-5.3, Fig. 5.1). In general, male seasonal ranges (Θ = 102-309 ha) were greater than female seasonal ranges (Θ = 36-112 ha), and historic deer ranges (Θ = 79-275 ha) were greater than present deer ranges (Θ = 34-172 ha). Similar results were found in comparing mean daily movements where sex, period, and age differed ($P < 0.002$), but season was found to be more similar ($P = 0.357$, Table 5.4). In general, male daily movements were greater than female daily movements, historic daily movements were greater than present daily movements, and adult and yearling daily movements were greater than fawn daily movements (Table 5.4).

Annual Movements

Results suggest that sex and period differed ($P = 0.004$) in describing Key deer annual ranges and core areas while age was not important ($P = 0.850$, Table 5.5, Fig. 5.2). In general, male annual ranges (Θ = 221-388 ha) were greater than female annual ranges (Θ = 42-101), and historic ranges (Θ = 101-388 ha) were greater than present ranges (Θ = 42-221 ha). In comparing mean daily movements, sex and period were found to differ in ($P < 0.001$) in describing daily movements while age was less important ($P = 0.589$, Table 5.5). Lastly, male daily movements were found to be greater than female daily movements, and historic daily movements were greater than present daily movements (Table 5.5).

Dispersal

Results suggest that annual male dispersal ($\Theta = 0.107$, SD = 0.056) was higher than annual female dispersal ($\Theta = 0.032$, SD = 0.047) between Big Pine and No Name keys. Approximately 33% of deer dispersing were < 2 years of age.

Table 5.1. Demographics of radio-collared Florida Key deer used to calculate annual and seasonal ranges and movements on Big Pine and No Name keys, 1968-72 and 1998-00.

Study		Annual	Seasonal
Sex	Age	*n*	*n*
Historic (1968-72)			
Female	Adult	13	13
	Yearling	6	7
	Fawn	0	6
	Total	19	26
Male	Adult	7	8
	Yearling	4	8
	Fawn	1	12
	Total	12	28
Total		31	54
Present (1998-00)			
Female	Adult	38	44
	Yearling	5	14
	Fawn	0	4
	Total	43	62
Male	Adult	19	34
	Yearling	2	10
	Fawn	1	3
	Total	22	47
Total		65	109
Grand Total		96	163

Table 5.2. Seasonal ranges (95% range, ha) for radio-collared Florida Key deer, 1968-72 and 1998-00.

							Tests[a]			
Sex	Age	Period	Season	*n*	Θ	SE	Sex	Age	Period	Season
Female	Adult	Current	Combined	188	41	3	A	A	A	
Female	Adult	Historic	Combined	49	79	5	A	A	B	
Female	Yearling	Current	Combined	25	44	7	A	A	A	
Female	Yearling	Historic	Combined	16	87	12	A	A	B	
Female	Fawn	Current	Combined	5	34	8	A	A	A	
Female	Fawn	Historic	Combined	7	129	68	A	A	B	
Male	Adult	Current	Combined	95	172	25	B	A	A	
Male	Adult	Historic	Combined	26	275	36	B	A	B	
Male	Yearling	Current	Combined	13	102	23	B	A	A	
Male	Yearling	Historic	Combined	13	127	14	B	A	B	
Male	Fawn	Current	Combined	6	25	9	B	A	A	
Male	Fawn	Historic	Combined	18	198	47	B	A	B	
Female	Combined	Current	Fall	42	36	4	A		A	A
Female	Combined	Current	Spring	64	50	7	A		A	A
Female	Combined	Current	Summer	57	40	3	A		A	A
Female	Combined	Current	Winter	55	38	4	A		A	A
Female	Combined	Historic	Fall	19	112	25	A		B	A
Female	Combined	Historic	Spring	18	82	11	A		B	A
Female	Combined	Historic	Summer	22	81	8	A		B	A
Female	Combined	Historic	Winter	13	62	3	A		B	A
Male	Combined	Current	Fall	19	216	89	B		A	A
Male	Combined	Current	Spring	34	125	18	B		A	A
Male	Combined	Current	Summer	43	177	38	B		A	A
Male	Combined	Current	Winter	18	102	19	B		A	A
Male	Combined	Historic	Fall	12	274	61	B		B	A
Male	Combined	Historic	Spring	18	169	33	B		B	A
Male	Combined	Historic	Summer	12	309	67	B		B	A

Table 5.2. Continued.

							Tests[a]			
Sex	Age	Period	Season	*n*	Θ	SE	Sex	Age	Period	Season
Male	Combined	Historic	Winter	15	155	21	B		B	A
$F_{1,3}$							85.89	2.47	16.36	2.54
P							0.000	0.086	0.000	0.056

[a]*F* and *P* values are for overall comparisons.

Table 5.3. Seasonal ranges (50% core area, ha) for radio-collared Florida Key deer, 1968-72 and 1998-00.

							Tests[a]			
Sex	Age	Period	Season	*n*	θ	SE	Sex	Age	Period	Season
Female	Adult	Current	Combined	188	7	0	A	A	A	
Female	Adult	Historic	Combined	49	11	1	A	A	B	
Female	Yearling	Current	Combined	25	9	2	A	A	A	
Female	Yearling	Historic	Combined	16	13	2	A	A	B	
Female	Fawn	Current	Combined	5	7	3	A	A	A	
Female	Fawn	Historic	Combined	7	29	18	A	A	B	
Male	Adult	Current	Combined	95	25	4	B	A	A	
Male	Adult	Historic	Combined	26	38	7	B	A	B	
Male	Yearling	Current	Combined	13	16	4	B	A	A	
Male	Yearling	Historic	Combined	13	19	3	B	A	B	
Male	Fawn	Current	Combined	6	2	1	B	A	A	
Male	Fawn	Historic	Combined	18	36	11	B	A	B	
Female	Combined	Current	Fall	42	5	1	A		A	A
Female	Combined	Current	Spring	64	9	1	A		A	A
Female	Combined	Current	Summer	57	6	1	A		A	A
Female	Combined	Current	Winter	55	6	1	A		A	A
Female	Combined	Historic	Fall	19	19	7	A		B	A
Female	Combined	Historic	Spring	18	12	2	A		B	A
Female	Combined	Historic	Summer	22	11	1	A		B	A
Female	Combined	Historic	Winter	13	9	1	A		B	A
Male	Combined	Current	Fall	19	28	11	B		A	A
Male	Combined	Current	Spring	34	19	3	B		A	A
Male	Combined	Current	Summer	43	27	7	B		A	A
Male	Combined	Current	Winter	18	14	3	B		A	A
Male	Combined	Historic	Fall	12	44	15	B		B	A
Male	Combined	Historic	Spring	18	21	4	B		B	A
Male	Combined	Historic	Summer	12	48	14	B		B	A

Table 5.3. Continued.

							Tests[a]			
Sex	Age	Period	Season	*n*	0	SE	Sex	Age	Period	Season
Male	Combined	Historic	Winter	15	25	4	B		B	A
$F_{1,3}$							55.39	1.02	9.48	1.94
P							0.000	0.362	0.002	0.123

[a]*F* and *P* values are for overall comparisons.

Table 5.4. Average daily movements (m) by season for radio-collared Florida Key deer, 1968-72 and 1998-00.

							Tests[a]			
Sex	Age	Period	Season	*n*	θ	SE	Sex	Age	Period	Season
Female	Adult	Current	Combined	188	294	9	A	A	A	
Female	Adult	Historic	Combined	49	398	14	A	A	B	
Female	Yearling	Current	Combined	25	299	22	A	A	A	
Female	Yearling	Historic	Combined	16	417	29	A	A	B	
Female	Fawn	Current	Combined	5	304	63	A	B	A	
Female	Fawn	Historic	Combined	7	396	64	A	B	B	
Male	Adult	Current	Combined	95	520	20	B	A	A	
Male	Adult	Historic	Combined	26	637	35	B	A	B	
Male	Yearling	Current	Combined	13	475	76	B	A	A	
Male	Yearling	Historic	Combined	13	549	42	B	A	B	
Male	Fawn	Current	Combined	6	231	34	B	B	A	
Male	Fawn	Historic	Combined	18	526	49	B	B	B	
Female	Combined	Current	Fall	42	277	16	A		A	A
Female	Combined	Current	Spring	64	307	17	A		A	A
Female	Combined	Current	Summer	57	296	13	A		A	A
Female	Combined	Current	Winter	55	291	18	A		A	A
Female	Combined	Historic	Fall	19	457	30	A		B	A
Female	Combined	Historic	Spring	18	389	27	A		B	A
Female	Combined	Historic	Summer	22	399	20	A		B	A
Female	Combined	Historic	Winter	13	346	12	A		B	A
Male	Combined	Current	Fall	19	544	51	B		A	A
Male	Combined	Current	Spring	34	482	30	B		A	A
Male	Combined	Current	Summer	43	487	31	B		A	A
Male	Combined	Current	Winter	18	516	61	B		A	A
Male	Combined	Historic	Fall	12	650	68	B		B	A
Male	Combined	Historic	Spring	18	571	51	B		B	A
Male	Combined	Historic	Summer	12	571	36	B		B	A

Table 5.4. Continued.

							Tests[a]			
Sex	Age	Period	Season	*n*	Θ	SE	Sex	Age	Period	Season
Male	Combined	Historic	Winter	15	549	36	B		B	A
$F_{1,3}$							192.83	6.08	45.79	1.08
P							0.000	0.002	0.000	0.357

[a]*F* and *P* values are for overall comparisons.

Table 5.5. Annual ranges (95% range and 50% core areas, ha) and average daily movements (m) for radio-collared Florida Key deer, 1968-72 and 1998-00.

						Tests[a]		
Sex	Age	Period	*n*	θ	SE	Sex	Age	Period
Range (95% Area)								
Female	Adult	Current	56	42	4	A	A	A
Female	Adult	Historic	17	107	24	A	A	B
Female	Yearling	Current	5	37	6	A	A	A
Female	Yearling	Historic	6	82	10	A	A	B
Male	Adult	Current	27	222	43	B	A	A
Male	Adult	Historic	9	340	72	B	A	B
Male	Yearling	Current	2	299	130	B	A	A
Male	Yearling	Historic	4	460	292	B	A	B
Male	Fawn	Current	1	39	--	B	A	A
Male	Fawn	Historic	1	530	--	B	A	B
Female	Combined	Current	61	42	4	A		A
Female	Combined	Historic	23	101	18	A		B
Male	Combined	Current	30	221	40	B		A
Male	Combined	Historic	14	388	90	B		B
$F_{1,2}$						49.81	0.16	8.45
P						0.000	0.850	0.004
Core Area (50% Area)								
Female	Adult	Current	56	6	1	A	A	A
Female	Adult	Historic	17	18	5	A	A	B
Female	Yearling	Current	5	6	2	A	A	A
Female	Yearling	Historic	6	10	2	A	A	B
Male	Adult	Current	27	33	8	B	A	A
Male	Adult	Historic	9	41	9	B	A	B
Male	Yearling	Current	2	47	5	B	A	A
Male	Yearling	Historic	4	97	72	B	A	B

Table 5.5. Continued.

						Tests[a]		
Sex	Age	Period	*n*	0	SE	Sex	Age	Period
Male	Fawn	Current	1	3	--	B	A	A
Male	Fawn	Historic	1	35	--	B	A	B
Female	Combined	Current	61	6	1	A		A
Female	Combined	Historic	23	16	4	A		B
Male	Combined	Current	30	33	7	B		A
Male	Combined	Historic	14	56	21	B		B
$F_{1,2}$						28.38	1.38	4.02
P						0.000	0.255	0.047
Mean Distance								
Female	Adult	Current	56	304	14	A	A	A
Female	Adult	Historic	17	399	19	A	A	B
Female	Yearling	Current	5	277	23	A	A	A
Female	Yearling	Historic	6	401	32	A	A	B
Male	Adult	Current	27	494	29	B	A	A
Male	Adult	Historic	9	631	46	B	A	B
Male	Yearling	Current	2	432	32	B	A	A
Male	Yearling	Historic	4	571	54	B	A	B
Male	Fawn	Current	1	277	--	B	A	A
Male	Fawn	Historic	1	789	--	B	A	B
Female	Combined	Current	61	302	13	A		A
Female	Combined	Historic	23	400	16	A		B
Male	Combined	Current	30	483	27	B		A
Male	Combined	Historic	14	625	35	B		B
$F_{1,2}$						81.28	0.53	27.06
P						0.000	0.589	0.000

[a]*F* and *P* values are for overall comparisons.

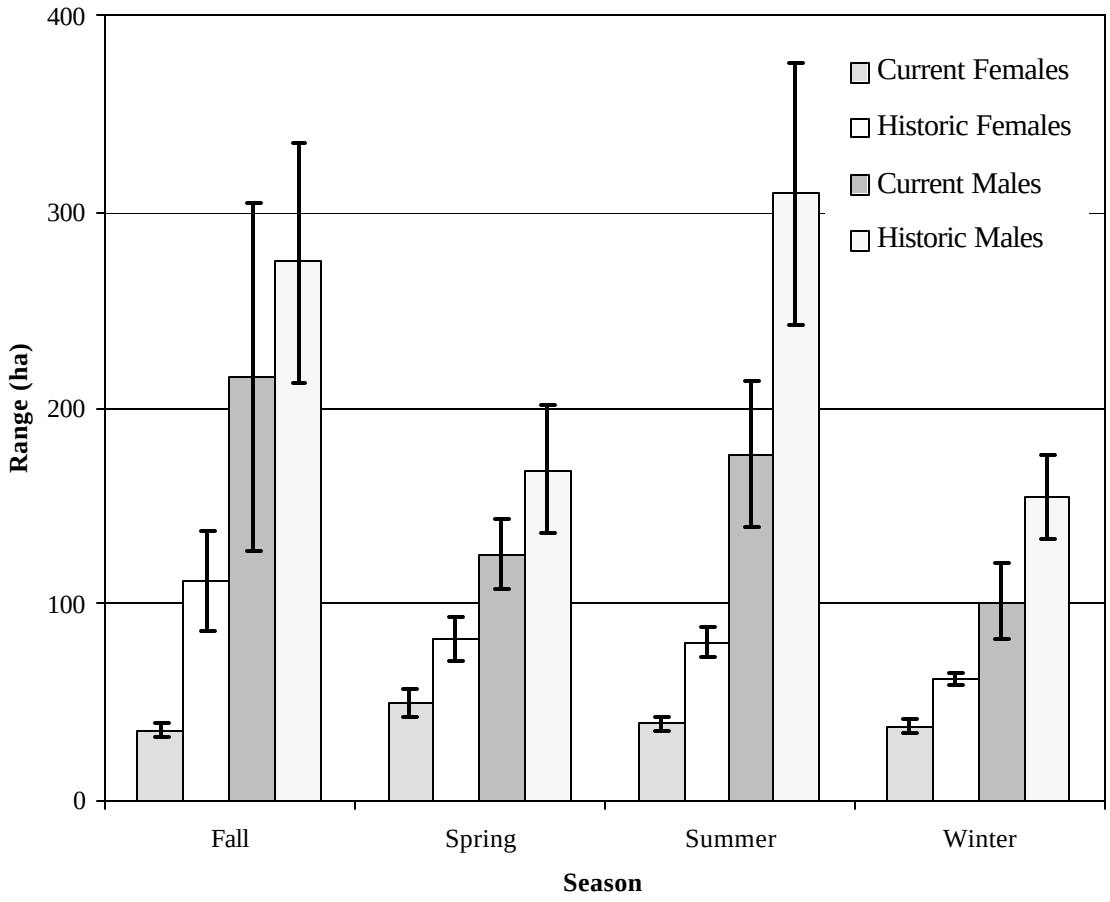


Fig. 5.1. Seasonal ranges (95% probability area) and error bars by sex and period.

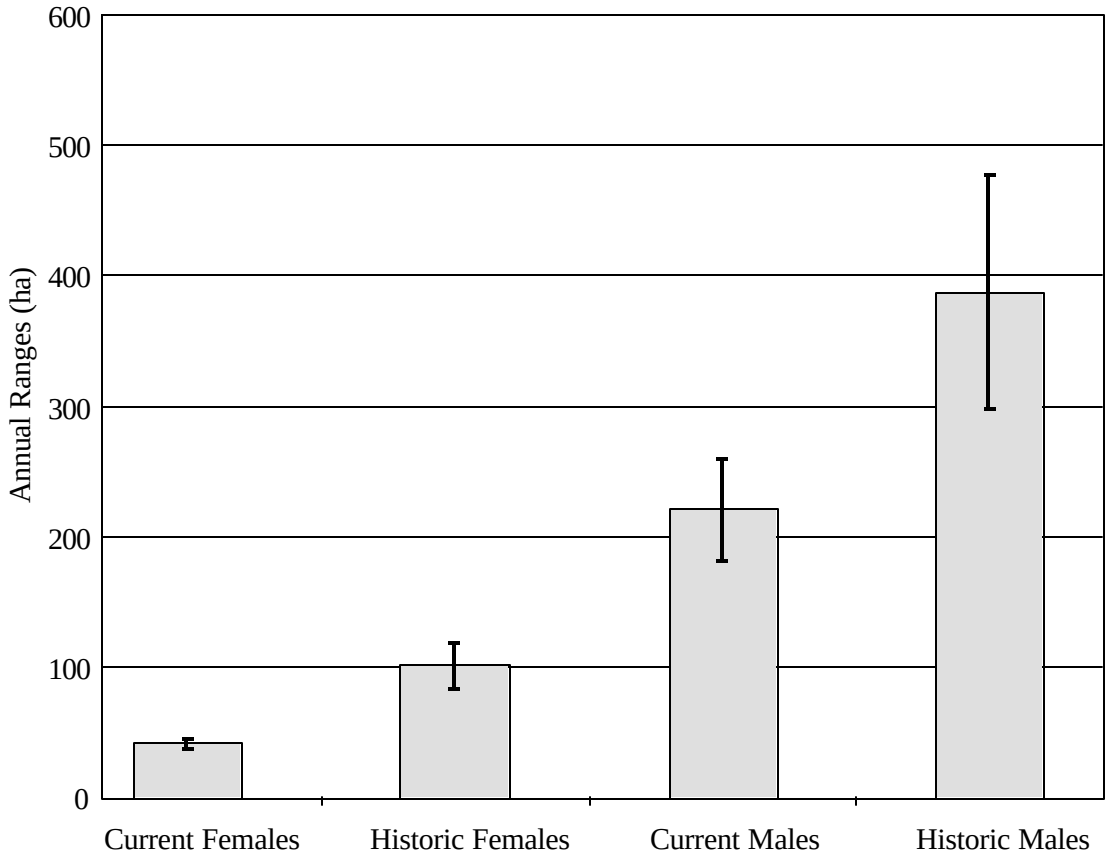


Fig. 5.2. Annual ranges (95% probability area) and error bars by sex and period.

DISCUSSION

No recent information about ranges and movements of the endangered Key deer were available before this study. In reviewing annual and seasonal ranges, core areas, and mean daily movements, some basic patterns became apparent. In general, sex and period (historic and present study) were important in describing ranges and movements of Key deer, whereas season and age were less important. The role of each of these factors in understanding Key deer movements will be discussed.

Season

Telemetry data suggest that ranges, core areas, and mean daily movements did not vary by season. Other studies of white-tailed deer reported that seasons can directly affected deer ranges and core areas. In northern climates, ranges tend to be larger and differ between seasons, while in milder climates little seasonal movements are normally observed (Marchinton and Hirth 1984, Demarais et al. 2000). The moderate climate in the Florida Keys is proposed to explain the lack of difference observed in seasonal Key deer ranges and movements. Climatic conditions in the Keys are characterized as tropical with summer rain (mean annual temperatures 25° C, mean annual precipitation 11 cm, Ross et al. 2000), which results in little difference between growing seasons (Folk 1991). Small seasonal differences observed in deer ranges and movements, though not statistically significant, are probably due to behavioral differences. Male ranges and movements increased during the pre-breeding and breeding season (Fig. 5.2) as males searched for receptive females. Numerous studies of white-tailed deer (Silvy 1975, Marchinton and Hirth 1984, Tierson et al. 1985, Beier and McCullough 1990, Demarais et al. 2000) have reported increases in male ranges and movements during the breeding season.

Sex

On average, male deer ranges and core areas were found to be significantly larger than female ranges and core areas (Table 5.5, Figs. 5.1-5.2). Larger male ranges have been reported in numerous white-tailed deer studies (Marchinton and Hirth 1984, Gavin et al. 1984, Mott et al. 1985, Tierson et al. 1985, Beier and McCullough 1990, Demarais et al. 2000). Demarais et al. (2000) reported that average male ranges are nearly double those of female ranges. Similar results were found in this study, where Key deer male ranges were 4-5 times greater than female ranges. In evaluating survival from radio-collared Key deer, differential survival between sexes was observed (female survival was higher than male survival, Chapter II).

Furthermore, approximately 50% of Key deer mortality are attributed to road mortality (Chapter II). Larger male ranges and movements might explain higher male road mortality due to an increase in risk (i.e., probability of being hit by a car, Chapter II, Silvy 1975).

Period

Ranges and daily movements for both males and females have decreased significantly in the last 30 years (Fig. 5.2). Reduction of movements can be explained by an increase of habitat quality due to development (i.e., greater edge, Chapter II) and/or an increase in the tameness of deer (Folk 1991, Folk and Klimstra 1991b, Miller and Ozoga 1997). Another explanation for a reduction in ranges and movements might be changes in population density. Several studies have found that increases in white-tailed deer populations have resulted in decreases in ranges due to intraspecific competition (Marchinton and Hirth 1984, Miller and Ozoga 1997, Lesage et al. 2000, Henderson et al. 2000). This is generally true for most mammals (Sanderson 1966). Silvy (1975) estimated the Key deer population to be 150-200 deer, or approximately 0.06 deer/ha, whereas the current deer population is estimated to be 482 deer, or 0.16 deer/ha (Chapter IV). Changes in both population density, habitat quality, and the taming of deer have resulted in a decrease in ranges and movements for this endangered deer herd.

Dispersal

Dispersal is an important mechanism in the stability and persistence of local populations (Akcakaya 2000). Previous studies have documented dispersal between islands for this white-tailed deer herd (Hardin 1974, Silvy 1975), but reliable estimates were lacking. In this study, annual male dispersal (%, θ = 0.107, SD = 0.056) was found to be greater than female dispersal (%, θ = 0.032, SD = 0.047) between Big Pine and No Name keys. Several studies have reported greater dispersal rates for male deer, particularly yearlings (Miller and Ozoga 1997, Rosenberry et al. 1999, Nelson and Mech 1999, Rosenberry et al. 2001). Reasons for high male dispersal include competition for food resources, antagonism of females toward maturing males (especially sons), and competition for breeding privileges (Miller and Ozoga 1997).

Recolonization of extirpated local populations is more likely to take place with younger animals, particularly male Key deer, which have been shown to readily disperse from natal sites (R. R. Lopez, personal observation). Such information is useful in the recovery of the Key deer, especially in understanding the extinction of some island populations. For example,

estimates of some outer islands found small deer numbers and skewed sex ratios, which might explain why certain local deer populations are not increasing (Chapter IV, R. R. Lopez, unpublished data). Future management strategies such as deer translocations might consider the sex and age of target animals to ensure the overall success of such strategies. For example, 3 adult female Key deer were experimentally translocated to Little Pine Key from No Name Key. Within 1 month of the translocation, 2 of the 3 deer returned to No Name Key across a 2.4-km channel (R. R. Lopez, unpublished data). The strong fidelity of translocated adult females to their natal sites suggests that future efforts might consider “soft” releases or the movement of family groups to increase the success of such programs (Nielson 1988).

CHAPTER VI

HURRICANE IMPACTS

SYNOPSIS

Hurricanes are a major natural disturbance affecting coastal areas in the southeastern United States. The role of hurricanes on the flora and fauna in the Florida Keys is of interest due to the relatively high frequency of tropical storm occurrences and the low land elevation (< 3 m) making these islands susceptible to storm surges. Hypothesized impacts to the Key deer herd include direct mortality or loss of individuals, and/or a reduction in herd productivity. Other potential impacts include changes to vegetation communities (e.g., windthrown trees, broken branches) and decreases in freshwater availability. Since 1968, researchers and biologists have studied the population ecology of this endangered deer herd. The landing of Hurricanes Georges (Category 2, 1998) and Irene (Category 1, 1999), in combination with an ongoing radio-telemetry study, offered a unique opportunity to evaluate the impacts of natural disturbances or catastrophes on an island population of white-tailed deer. The objectives of this study were to (1) determine post-hurricane deer mortality, (2) compare herd productivity pre- and post-hurricane years, (3) evaluate deer monthly ranges, core areas, and mean daily movements during hurricane and non-hurricane years, and (4) determine changes in freshwater availability due to the associated storm surge. A total of 53 (female, n = 29; male, n = 24) and 45 (female, n = 27; male, n =18) deer were radio-collared during Hurricanes Georges and Irene, respectively. During Hurricane Georges, 1 adult male drowned due to the storm, representing 1.9% of radio-collared deer. For Hurricane Irene, no radio-collared deer died during the storm. A comparison of productivity estimates between years found a significant (P < 0.001) increase in fawn:doe estimates in 1999 and 2000. The average fawn:doe ratio observed between 1995-98 was 0.31, while the average fawn:doe ratio observed post-hurricane years doubled to 0.64. No significant difference was found in comparing core areas and mean daily distances between years for both storm events, however, significantly larger ranges (95% probability area) were observed for both males and females following Hurricane Georges. Fifteen waterholes (Big Pine, n = 13; Big Torch, n = 1; Middle Torch, n = 1) were monitored monthly following Hurricane Georges, and, due to the storm surge, 26.7% (4/15) of waterholes were found to be unsuitable for deer use. Many waterholes, however, were not unsuitable immediately after the

storm but rather several weeks or months later. Results from this study suggest that mild to moderate hurricanes (Category 1-2) have little direct impact on the survival of Key deer, however, stronger storms (> Category 3) would be expected to have a greater impact due to stronger winds and greater storm surge (> 3.5 m).

INTRODUCTION

It has long been reported that hurricanes or tropical storms might have a negative impact on the Key deer population (Klimstra et al. 1971, Silvy 1975, Seal and Lacy 1990). Historically, hurricanes have been one of the major types of natural disturbances affecting coastal areas in the United States, particularly in the Caribbean islands (Boose et al. 1994, Ross et al. 2000). The role of hurricanes on the flora and fauna of the Florida Keys is of interest due to the relatively high frequency of tropical storm occurrences, and the low land elevations (< 3 m), which make these islands susceptible to storm surges (Folk 1991, Ross et al. 2000). At the landscape level, hurricanes have a potential of reshaping shorelines, causing extensive damage to vegetation in forested areas, and changing hydrological properties (Boose et al. 1994, Ross et al. 2000). Hypothesized impacts to the deer herd includes direct mortality or loss of individuals and/or a reduction in herd productivity (Folk 1991, Labisky et al. 1999). Other potential impacts include changes to vegetation communities (windthrown trees, broken branches) and a decrease in freshwater availability. In the case of the latter, freshwater is a limiting factor for Key deer and a significant storm surge may limit the amount of freshwater available in the form of natural waterholes (Folk 1991).

Since 1968, researchers and biologists have studied the population ecology of this endangered deer herd. Hurricanes, though a rather common occurrence in the Keys, rarely have resulted in a direct hit within the narrow range (< 15 km) of the deer population (Chapter I). In January 1998, a research project was initiated to evaluate the current status of the Key deer population. In that same year, the center of Hurricane Georges (Category 2) passed through the lower Florida Keys, directly within the deer range (Guiney 1998). The following year, a less substantial storm, Hurricane Irene, also landed directly within the Key deer range (Avila 1999, Fig. 6.1). The landing of these 2 hurricanes, in combination with an ongoing radio-telemetry study, offered a unique opportunity to evaluate the impacts of

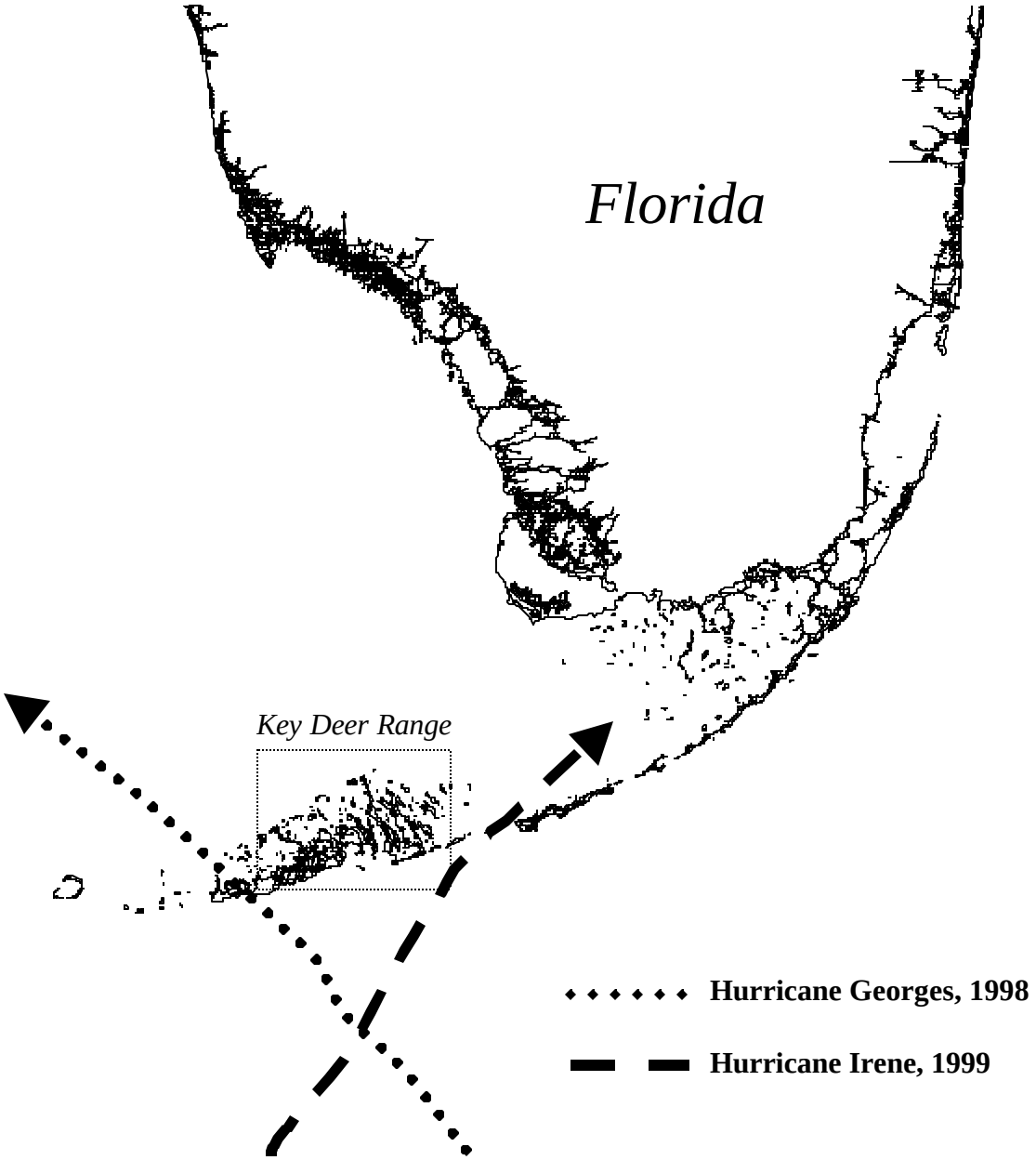


Fig. 6.1. Direction of Hurricanes Georges and Irene in the Florida Keys, 1998-99.

violent natural disturbances or catastrophes to an island population of white-tailed deer. An understanding of the mortality, movements, and impacts to natural resources such as vegetation and freshwater would aid in the management and recovery of this endangered deer population. Furthermore, such information also would be useful (Boyce 1992, Akcakaya 2000) in the implementation of a PVA being proposed for the Key deer. Thus, the objectives of this study were to (1) determine post-hurricane deer mortality, (2) compare herd productivity pre- and post-hurricane years, (3) evaluate deer monthly ranges, core areas, and mean daily movements during hurricane and non-hurricane years, and (4) determine changes in freshwater availability due to the associated storm surge.

METHODS

Key deer were radio-collared as part of a research project conducted January 1998-December 2000 on Big Pine and No Name keys. All survival and movement data described in this chapter were collected on these 2 islands (Chapter I). Furthermore, freshwater availability was evaluated on Big Pine in addition to the neighboring islands of Big Torch (625 ha) and Middle Torch (409 ha) keys.

Hurricanes

The Saffir-Simpson Hurricane scale is a 1-5 rating of hurricane intensity: (1) Category 1 (winds 119-153 km/hr, storm surge = 1.5 m), (2) Category 2 (winds 154-177 km/hr, storm surge = 2 m), (3) Category 3 (winds 178-209 km/hr, storm surge = 3.5 m), (4) Category 4 (winds 210-249 km/hr, storm surge = 5 m), and (5) Category 5 (winds > 249 km/hr, storm surge > 6 m, Neumann 1991). Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf in the landfall region. Hurricanes Georges and Irene were Categories 2 and 1, respectively (Guiney 1998, Avila 1999).

Hurricane Georges.—Hurricane Georges (strong category 2) made landfall on 25 September 1998 in Key West, Florida with minimum central pressure of 981 mb and maximum sustained 2-minute winds of 178 km/hr. The storm surge was estimated to be approximately 1.75 m in the Florida Keys. Rainfall in the Keys was considerably less than what was seen over Cuba or Hispaniola, with Key West recording an average daily rainfall of 3.3 cm. An estimated $104 million dollars was spent on relief services in the United States following the aftermath of Hurricane Georges, making it one of the most expensive hurricanes in recent years (Guiney

1998).

Hurricane Irene.—The center of then Tropical Storm Irene crossed the Havana and Ciudad Havana provinces on 14 October 1999. Irene reached hurricane status (moderate Category 1) over the Florida Straits with the center of the storm moving over Key West, Florida on 15 October 1999. A minimum central pressure of 986 mb, maximum sustained 2-minute winds of 127 km/hr, and a storm surge of approximately 0.5 m above normal were recorded for Hurricane Irene in the Keys. Average daily rainfall in Key West was 3.6 cm. Damage to trees and personal property was observed following the aftermath of Hurricane Irene, however, not to the same extent as Hurricane Georges (Avila 1999).

Radio Telemetry

Key deer were monitored via radiotelemetry before and after both hurricanes. Deer were captured and radio-collared using portable drive nets, drop nets, and hand capture (Silvy 1975, Silvy et al. 1975, Lopez et al. 1998) between January 1998-December 2000. Captured deer were marked using plastic neck collars (8-cm wide, primarily females of all age-classes), leather antler collars (0.25-cm wide, yearling and adult males only), or elastic expandable neck collars (3-cm wide, primarily male fawns/yearlings). A battery-powered mortality-sensitive radio transmitter (150-152 MHz, 100-110 g for plastic neck collars, 10-20 g for antler transmitters and elastic collars, Advanced Telemetry Systems, Isanti, Minnesota, USA) was attached to collar material. In addition, each captured animal received an ear tattoo, which served as a permanent marker (Silvy 1975).

Radio-collared deer were monitored 6-7 times per week at random intervals (24-hour period was divided into 6 equal 4-hour segments; one 4-hour segment was randomly selected and during that time all deer were located, Silvy 1975). Deer locations were determined via homing and triangulation (Silvy 1975, White and Garrott 1990). Telemetry locations were entered into a GIS using ArcView (Version 3.2) and Microsoft Access (Version 97).

Productivity Estimates

Since 1988, USFWS biologists have conducted intense October fall counts (5-7 nights) along 56-km route (Big Pine and No Name keys) to estimate fawn production (fawn:doe ratio estimates, Chapter IV). These productivity estimates, determined by dividing the total number of fawns seen during a survey by the total number of adult does seen during a survey, serve as a crude index to herd productivity.

Water Availability

Previous studies reported that Key deer can drink brackish water up to 15 ppt (Klimstra et al. 1974, Folk 1991). Water quality was monitored monthly pre- and post-hurricanes to determine waterhole suitability (< 15 ppt) for deer from 15 waterholes on Big Pine (n = 13), Middle Torch (n = 1), and Big Torch (n = 1) keys. For each waterhole, salinity was measured and recorded monthly using a Yellow Springs Instrument (YSI) conductivity/salinity meter (Model 33, YSI Yellow Springs, Ohio, USA).

Data Analysis

Direct mortality due to each hurricane was determined from radio-collared deer by dividing the number of radio-collared deer that died in each storm (1-week post-storm) by the total number of radio-collared deer alive prior to the storm. Deer mortality that occurred during the 1-week post-storm period that was not directly related to the hurricane (e.g., roadkill deer) were not included in the calculation.

Key deer ranges (95% probability area) and core areas (50% probability area) were calculated using a fixed kernel home range estimator (Worton 1989, Seaman et al. 1998, Seaman et al. 1999) with the animal movement extension ArcView, Version 3.2 (Hooge and Eichenlaub 1999). Calculation of the smoothing parameter (kernel width) as described by Silverman (1986) was used in generating kernel range estimates. Ranges (ha), core areas (ha), and mean daily movements (m) were calculated by sex for a 3-week period following each storm. Key deer movements by age-class were not evaluated due to small sample sizes (White and Garrott 1990). For example, Hurricane Georges occurred on 25 September 1998, therefore, ranges, core areas, and mean daily distances were calculated between 25 September-15 October. This allowed the comparison of deer movements following the aftermath of each storm to identical periods in other years when a storm did not occur. Because Hurricane Irene landed on 15 October 1999, movement data could not be extended beyond that date for comparing movements for Hurricane Georges. In other words, deer ranges from 2 different storms would then be compared due to the time overlap. Thus, the time period used for Hurricane Irene was 15 October-5 November. Differences in ranges, core areas, and mean daily movements were tested using an ANOVA, and Tukey's HSD for multiple comparisons was used to separate means when F-values were significant ($P \leq 0.05$, Ott 1993).

Average productivity (fawn:doe ratio estimates, fall counts) were determined by year between 1995-00. Differences in productivity estimates also were tested using an ANOVA,

and Tukey's HSD for multiple comparisons also was used to separate means when *F*-values were significant ($P \leq 0.05$, Ott 1993).

Water salinity for 15 selected waterholes within the range of the Key deer (Big Pine, Middle Torch, and Big Torch keys) were measured for 6-months following Hurricane Georges. Waterhole salinity following Hurricane Irene was not measured due to the insignificant storm surge (< 0.5 m) associated with that storm (Avila 1999). Water salinity measurements were compared to historic salinity measurements (1988-90, no hurricanes occurred during this period) for identical or paired waterholes using a 2 sample *t*-test (Folk 1991, Ott 1993). The percent of fresh waterholes that were unsuitable for deer (> 15 ppt) due to the storm surge was determined. Furthermore, the location of waterholes (upland versus lowlands) was evaluated using ArcView to determine waterhole susceptibility to a storm surge at lower elevations. Uplands vegetation types were defined as those $\geq$ 1 m above mean sea level, which typically are not influenced by tides (e.g., pinelands, hammocks), whereas, lowlands were $\leq$ 1 m above mean sea level and susceptible to flooding (e.g., buttonwoods, freshwater marsh, Chapter I, Folk 1991).

RESULTS

Mortality

Fifty-three (female, n = 29; male, n = 24) and 45 (female, n = 27; male, n =18) radio-collared deer were available during Hurricanes Georges and Irene, respectively. During Hurricane Georges, 1 adult male drowned due to the storm, representing 1.9% of radio-collared deer. For Hurricane Irene, no radio-collared deer died during the storm.

Productivity

Forty-two surveys were conducted during October 1995-00, within a range of 5-8 surveys per year. A comparison of productivity estimates between years found a significant ($P < 0.001$) increase in fawn:doe estimates in 1999 and 2000 (Fig. 6.2). The average fawn:doe ratio observed between 1995-98 was 0.31, while the average fawn:doe ratio observed post-hurricane years doubled to 0.64.

Movements

One hundred (females, n = 66; males, n = 34) and 90 (females, n = 62; males, n = 28) radio-collared Key deer were used to calculate deer movements (ranges, core areas, and daily distances) for Hurricane Georges and Irene, respectively (Table 6.1). The average number of locations used to calculate ranges, core areas, and mean daily movements was 15 (SD = 3, range = 10-21) with a total of 3,177 radio locations. As expected, differences in ranges, core areas, and daily distances were found between sexes for both storm events (Chapter V, Table 6.1). No significant difference ($P > 0.076$) was found in comparing core areas and mean daily distances before and after for both storm events, however, significantly ($P = 0.020$) larger ranges (95% probability area) were observed for both males and females following Hurricane Georges (Table 6.1).

Water Availability

In reviewing historical salinity data for waterholes that were monitored in this study, all waterholes were suitable (< 15 ppt) for Key deer (Table 6.2) prior to Hurricane Georges. Following the storm, water salinity measurements for 26.7% (4/15) of waterholes being monitored were found to be unsuitable for deer use (Table 6.2, Folk 1991). Many waterholes, however, were not unsuitable immediately following the storm but rather several weeks or months later (Fig. 6.3). Fifty percent (3/6) of monitored waterholes found within lowland areas were impacted by the storm surge whereas 11% (1/9) of upland waterholes were impacted. Waterholes that were impacted eventually returned to a lower salinity. In reviewing permanent waterholes on these 3 islands, approximately 64% (91/142) of all waterholes were found in upland areas (Fig. 6.4, Chapter I).

Table 6.1. Post-hurricane Key deer movements (mean distance, 95% kernel, and 50% kernel ranges) for Hurricane Georges (25 September –15 October 1998) and Irene (15 October– 5 November 1999).

						Tests [a]	
	Sex	Year	*n*	0	SD	Sex	Year
Hurricane Georges							
Distance	Female	1998[b]	25	310	195	A	A
	Female	1999	24	268	99	A	A
	Female	2000	17	310	129	A	A
	Male	1998[b]	21	552	230	B	A
	Male	1999	13	431	277	B	A
	$F_{1,2}$					24.28	1.58
	P					0.000	0.211
95% Area	Female	1998[b]	25	60	78	A	A
	Female	1999	24	30	26	A	B
	Female	2000	17	44	29	A	B
	Male	1998[b]	21	184	150	B	A
	Male	1999	13	88	96	B	B
	$F_{1,2}$					23.31	4.06
	P					0.000	0.020
50% Area	Female	1998	25	10	14	A	A
	Female	1999	24	6	6	A	A
	Female	2000	17	8	6	A	A
	Male	1998	21	29	24	B	A
	Male	1999	13	16	19	B	A
	$F_{1,2}$					19.64	2.65
	P					0.000	0.076

Table 6.1. Continued.

	Sex	Year	*n*	0	SD	Tests[a] Sex	Tests[a] Year
Hurricane Irene							
Distance	Female	1998	24	277	131	A	A
	Female	1999[b]	23	290	140	A	A
	Female	2000	15	350	196	A	A
	Male	1998	16	426	143	B	A
	Male	1999[b]	12	421	122	B	A
	$F_{1,2}$					16.34	1.20
	P					0.000	0.307
95% Area	Female	1998	24	37	37	A	A
	Female	1999[b]	23	34	28	A	A
	Female	2000	15	59	60	A	A
	Male	1998	16	90	81	B	A
	Male	1999[b]	12	95	53	B	A
	$F_{1,2}$					20.63	1.20
	P					0.000	0.307
50% Area	Female	1998	24	6	5	A	A
	Female	1999[b]	23	7	6	A	A
	Female	2000	15	11	13	A	A
	Male	1998	16	14	17	B	A
	Male	1999[b]	12	13	10	B	A
	$F_{1,2}$					9.81	1.28
	P					0.002	0.284

[a]*F* and *P* values are for overall comparisons.

[b]Year hurricane occurred.

Table 6.2. Water salinity of 15 selected waterholes within the range of the Key deer pre- and post-Hurricane Georges, 1988-98.

Island	ID	Period	*n*	Θ	SD	*P* [a]
Big Pine	1	Current	8	11.88	6.94	0.090
Big Pine	1	Historic	14	6.86	3.23	
Big Pine	2	Current	6	3.00	2.45	0.210
Big Pine	2	Historic	13	1.00	0.91	
Big Pine	3	Current	8	3.50	0.54	0.010
Big Pine	3	Historic	25	2.76	0.88	
Big Pine	4	Current	7	7.57	3.41	0.092
Big Pine	4	Historic	6	4.50	2.51	
Big Pine	5	Current	7	5.71	2.69	0.066
Big Pine	5	Historic	10	9.00	4.11	
Big Pine	6	Current	6	9.17	1.47	0.940
Big Pine	6	Historic	6	9.33	4.97	
Big Pine	7	Current	6	11.17	6.24	0.071
Big Pine	7	Historic	6	5.33	0.52	
Big Pine	8	Current	8	24.00	6.91	0.000 **
Big Pine	8	Historic	5	2.80	0.45	
Big Pine	9	Current	8	1.63	0.74	0.920
Big Pine	9	Historic	27	1.59	0.93	
Big Pine	10	Current	8	19.70	12.30	0.041 **
Big Pine	10	Historic	28	8.71	4.78	
Big Pine	11	Current	8	5.37	1.60	0.007
Big Pine	11	Historic	6	3.25	0.50	
Big Pine	12	Current	8	15.40	11.90	0.210 **
Big Pine	12	Historic	8	9.13	5.22	
Big Pine	13	Current	8	3.63	4.00	0.049
Big Pine	13	Historic	9	9.78	7.28	
Big Torch	14	Current	7	7.57	2.64	0.002
Big Torch	14	Historic	14	2.21	0.70	

Table 6.2. Continued.

Island	ID	Period	*n*	0	SD	*P* [a]
Middle Torch	15	Current	7	19.00	7.02	0.053 **
Middle Torch	15	Historic	6	12.50	1.00	

[a] Waterholes with asterisk represent change in salinity to the point where no longer valuable to Key deer (> 15 ppt).

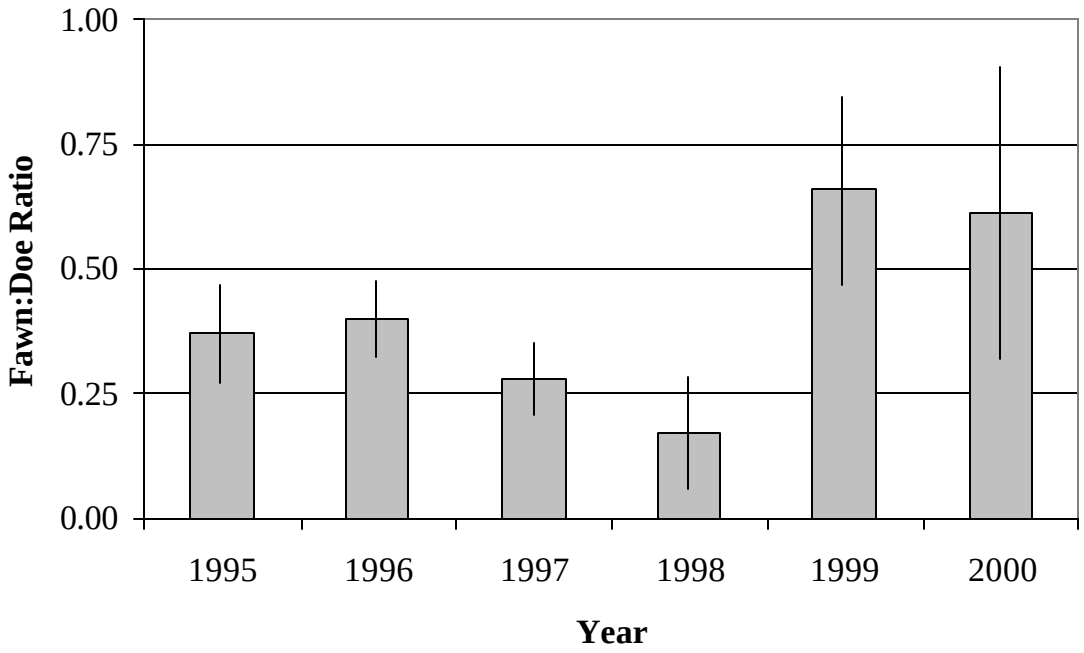


Fig. 6.2. Annual USFWS fawn counts (October) with standard error bars.

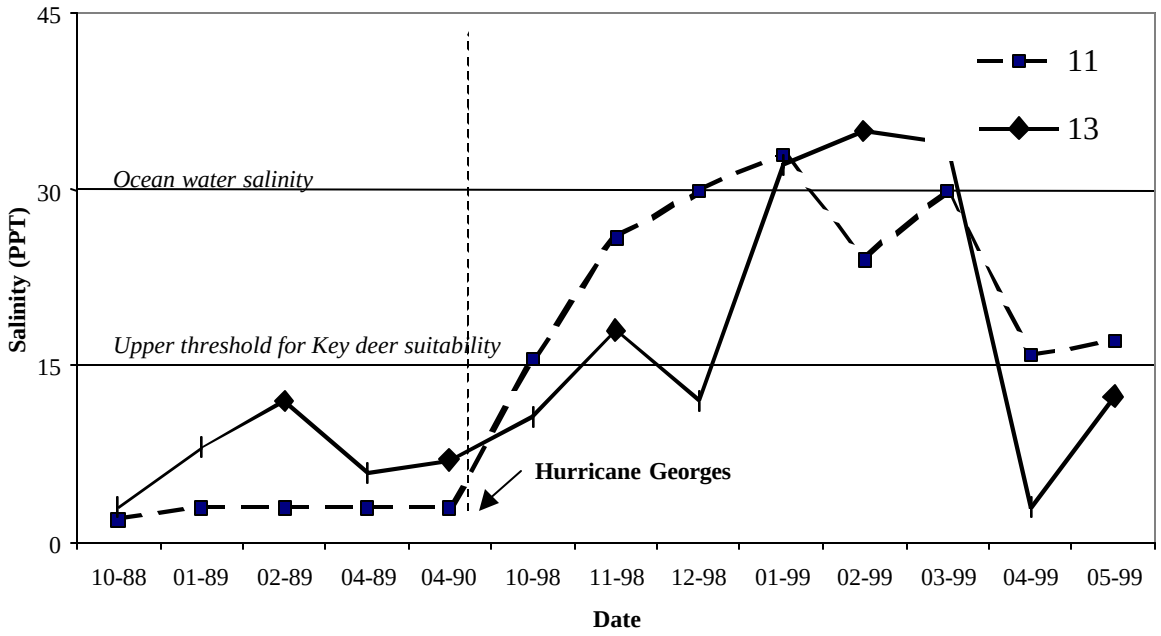


Fig. 6.3. Example of 2 waterholes impacted by storm surge of Hurricane Georges.

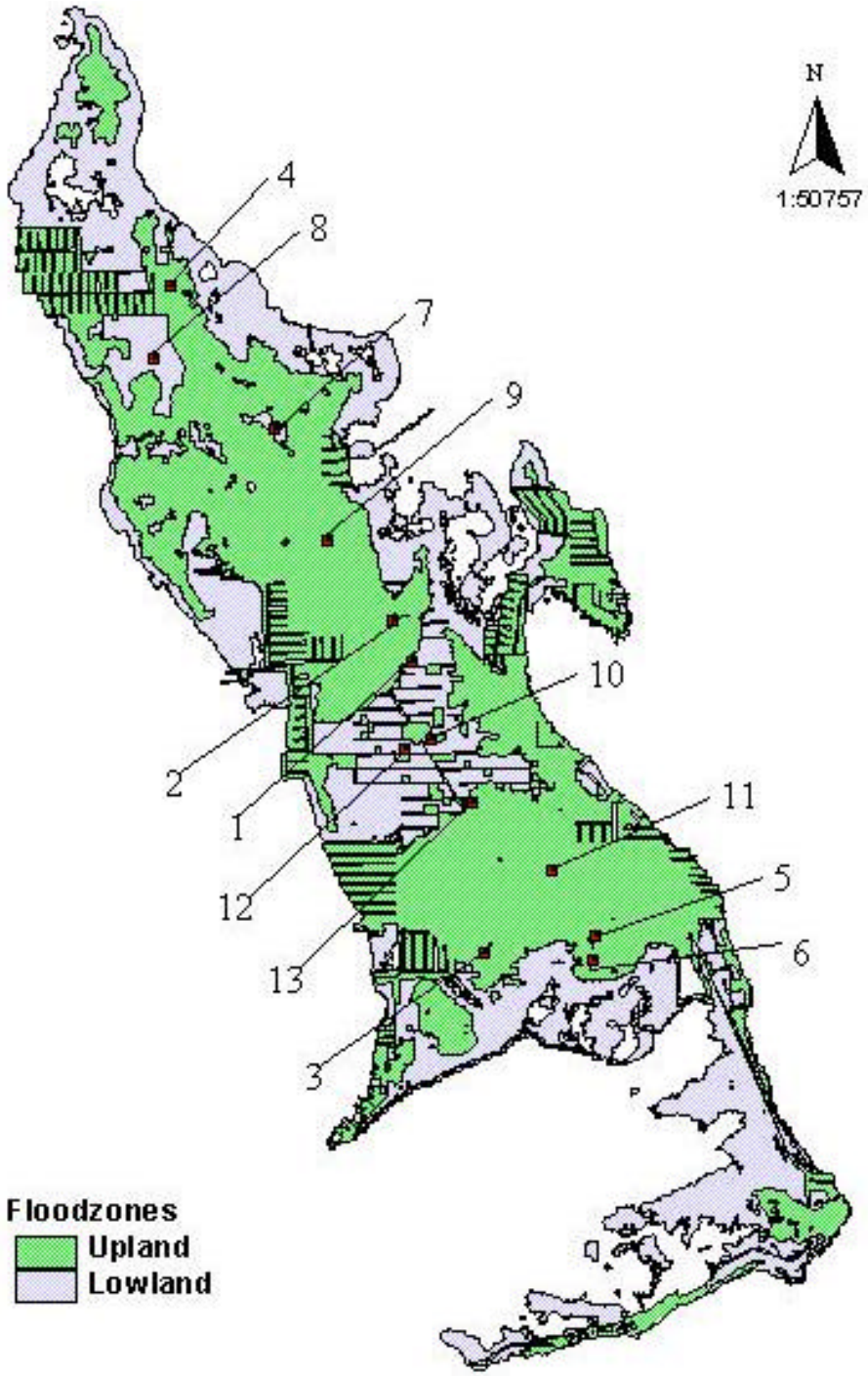


Fig. 6.4. Monitored waterholes on Big Pine Key by elevation.

DISCUSSION

Mortality

The landing of Hurricanes Georges and Irene in combination with an ongoing radio-telemetry study offered a unique opportunity to evaluate the effects of violent natural catastrophes to an island population of white-tailed deer. Results from the study found that Key deer mortality due to the storms was surprisely low (< 2%). Three major forces contribute to damage caused by a hurricane: winds, storm surge, and rain (Labisky et al. 1999). Winds and storm surges are of particularly concern in the Keys due to the low elevation of these islands (highest point < 3 m), and the potential negative impact to flora and faunal communities. For example, during Hurricane Georges many of the areas occupied by Key deer were submerged due to the storm surge for several hours (R. R. Lopez, personal observation). Many smaller islands that support small deer populations such as Munson Island or Annette Key, were completely inundated as well. Previous studies have noted that Key deer are strong swimmers (Folk 1991), which suggests that, for a few hours during the storm, Key deer might have been forced to tread water until the storm surge subsided. Few studies on the impacts of hurricanes on white-tailed deer populations exist, however, Labisky et al. (1999) reported 100% survival for radio-collared white-tailed deer in the Everglades following the aftermath of Hurricane Andrew (Category 4, 1992). Results from this study suggest that mild to moderate hurricanes (Category 1-2) have little direct impact on the Key deer population, but stronger storms (> Category 3) would be expected to have a greater impact due to stronger winds and greater storm surge (> 3.5 m, Neumann 1991). For example, a moderate Category 3 hurricane with a storm surge of 4 m would result in the complete submersal of Big Pine and No Name keys. The majority of the deer population is supported on these islands, in addition to the bulk of the freshwater (Chapters I and IV). Hence, a strong hurricane might limit freshwater availability following the storm, causing a decline in the Key deer population. It also is possible that rain following the storm surge may neutralize or minimize the effects of the storm surge.

Productivity

Study results suggest that Key deer productivity nearly doubled following Hurricane Georges (Fig. 6.2). On Big Pine and No Name keys, the majority of the overstory component was reduced approximately by 50% due to strong winds and windthrown trees (R. R. Lopez, personal observation). This reduction in the overstory is proposed to have resulted in both an immediate and long-term effect in the amount of food available to Key deer. For example, the

reduction in the overstory was observed to have caused (1) an increase in the amount of food available from windthrown trees and/or broken branches, and (2) an increase in re-growth or sprouting that also provided additional food for Key deer. Other studies have reported an increase in understory vegetation following tropical storms or hurricanes (Ross et al. 1997, Ross et al. 1998, Wallace 1998). It is proposed the observed increase in herd productivity is due to an increase in the overall fitness of female Key deer resulting from higher food availability prior to the breeding season (Verme and Ullrey 1984, Fig. 6.2). Results from this study differed from Labisky et al. (1999), who reported a decrease in Everglades' deer productivity following Hurricane Andrew. A possible explanation might be that vegetation types in the Florida Everglades consist primarily of wet prairie with limited to no overstory (Miller 1993, Labisky et al. 1999). Conversely, dense hammocks and open pinelands characterize upland vegetation types in the Florida Keys (Chapter I, Folk 1991). In the case of hardwood hammocks, strong winds opened the dense forest canopy which caused a flush of new understory growth (R. R. Lopez, personal observation). Such results would not be expected in the Everglades ecosystem due to the lack of a forest canopy.

Movements

Deer movements (ranges, core areas, and daily distances) were compared by year and sex to determine effects of hurricanes on the Key deer population. As expected, differences in ranges, core areas, and daily distances were found between sexes (Chapter V, Table 6.1). This difference is well documented in the literature (Marchinton and Hirth 1984, Beier and McCullough 1990, Demarais et al. 2000) and attributed to behavioral differences between sexes (in general, males have greater ranges and move greater distances, Chapter V). No significant difference was found in comparing core areas and mean daily distances between years for both storm events, however, significantly larger ranges (95% probability area) were observed for both males and females following Hurricane Georges (Table 6.1). Two reasons might explain the increase in ranges for both sexes. First, following Hurricane Georges, an increase in traffic was observed, particularly emergency clean-up crews with heavy machinery (R. R. Lopez, personal observation). A tremendous amount of debris was collected for 2-3 months following the storm, which might have caused an increase in deer movements due to the fact that they were startled by heavy equipment. Second, freshwater availability was reduced in areas of low elevation, forcing some deer to move greater distances to obtain needed freshwater. For example,

freshwater in the southernmost area of Big Pine (Cactus Hammock) was limited (R. R. Lopez, personal observation), possibly causing Key deer to move greater distances.

Water Availability

Following the storm, water salinity measurements for 26.7% (4/15) of waterholes being monitored were found to be unsuitable (Table 6.2). Interestingly, many of the monitored waterholes did not become unsuitable for Key deer immediately following the storm but rather several weeks or months later (Fig. 6.3). Saltwater has a greater density than freshwater causing the latter to separate and form an upper lense (Folk 1991). It is hypothesized that following Hurricane Georges, rainfall quickly recharged the upper portion of waterholes with freshwater. However, as the dry season approached (November-February) several months later, evaporation caused an increase in water salinity due to (1) an overall decrease in freshwater available, and (2) an increase in salt concentration due to evaporation causing a hypersaline situation (> 30 ppt, salinity of ocean water, Fig. 6.3, Folk 1991). Thus, freshwater may not be limiting to Key deer until several weeks or months following a hurricane event.

Fifty percent (3/6) of monitored waterholes found in wetlands were impacted due to the storm surge. This suggests islands with low elevation areas, such as Cudjoe or Sugarloaf, might not sustain stable deer populations over a long period of time due to the limited amount of freshwater that would be expected in the event of a hurricane. This also suggests that islands such as Big Pine Key are important to the overall viability of the deer herd due to the high number of fresh waterholes in upland areas (Chapter I). For example, in reviewing permanent waterholes on Big Pine, Big Torch, and Middle Torch keys, approximately 64% (91/142) of all waterholes were found in upland areas.

Management Implications

Key deer have evolved in a unique environment subject to violent natural disturbances or catastrophes. Despite the small impacts observed in this study, more severe storms (> Category 3) would be expected to have a greater impact to the deer population. In the future, a captive propagation program should be implemented to enhance the overall herd viability (stock can be used to restock the range in the event of a hurricane) using surplus animals. Ultimately, the only real insurance policy for the Key deer population is an alternative refuge protected from natural disturbances such as hurricanes.

CHAPTER VII

DEMOGRAPHIC AND SPATIALLY STRUCTURED POPULATION MODEL

SYNOPSIS

Rapid development and urbanization in the Florida Keys is altering the landscape and threatening the deer population with extinction. In 1998, a planning process was initiated to draft and submit a regional HCP for the Key deer on Big Pine and No Name keys. In this HCP, a structured model approach was selected to address the following study objectives to aid in making conservation decisions for these 2 islands. Specific objectives include: (1) develop a demographic and spatially structured model to be used as a conservation-planning tool in the Key deer HCP, (2) conduct a sensitivity analysis to identify model parameters which account for the greatest uncertainty in order to plan future field research, and (3) provide users of the model with an array of risk estimates based on different development scenarios. Data used to estimate model parameters were derived from several sources. Population demographics were collected via radiotelemetry, survey data, and deer necropsies. Spatial data such as vegetation and ownership patterns were obtained from county, state, and federal agencies. The analysis of the Key deer metapopulation involved a series of simulations, with each scenario consisting of 10,000 replications for 100 time steps (years). Five development scenarios were evaluated using the model. With most parameter combinations, the model predicted a low risk of decline for the Key deer population. For example, the risk of the deer metapopulation falling below 25 individuals in 50 years ranged from 0.5-5.2% depending on the development scenario. Model results were most sensitive to the maximal growth rate estimate (R_{max}), and the probability and hypothesized impacts of severe hurricanes (Category 4-5). Model refinement can occur with the collection of better parameter estimates. In addition, users of the model were provided with an array of risk estimates and other assessment end-points, and a framework to plan the future of these 2 islands and this endangered deer herd. The model also serves as an important management tool for the endangered Key deer and even other populations of white-tailed deer.

INTRODUCTION

The Overseas Highway (US 1) links the small islands in the Keys to peninsular Florida. The safe and expedient evacuation during state emergencies such as tropical storms or hurricanes is dependent on traffic movement on US 1. In 1995, due to the inadequate level of service on the US 1 segment servicing Big Pine and No Name keys, a building moratorium was established until highway improvements could be implemented (Chapter I, Calvo 1996). Highway improvements such as widening the intersection or adding a third northbound lane could improve the level of service on US 1 and lift the building moratorium, however, such activities also could impact the deer population. In 1998, a planning process began with FDOT, Monroe County, and DCA agency representatives to draft and submit a regional HCP for the Key deer. In this HCP, future development is being evaluated in terms of impacts to the deer population.

A PVA is a method or a collection of methods used to evaluate the viability of threatened or endangered species using computer simulation models (Boyce 1992, Burgman et al. 1993). Species viability is often expressed as the risk or probability of extinction, population decline, expected time to extinction, or expected chance of recovery (Akcakaya and Sjogren-Gulve 2000). PVA models attempt to predict such measures based on demographic and habitat data.

Structured models (sometimes referred to as frequency-based models) group individuals in a population according to age or morphological characteristics, allowing vital rates (survival and fecundity) by age- or stage-class to be incorporated in the model (Akcakaya 2000). A transition matrix is commonly used in structured models (Caswell 2000). Advantages of structured models include the ability to incorporate stochasticity in vital rates, the effect of population size (density dependence), and differences in discrete populations (Akcakaya 2000). In the case of the latter, a collection of discrete or local populations is often referred to as a metapopulation (Gilpin and Hanski 1991). Metapopulation models can be constructed by adding information about the spatial structure of local populations (e.g., number of populations, size, shape, and habitat connectivity). Furthermore, habitat analyses that link landscape-scale data also can be incorporated in structured models (Akcakaya 2000).

Compared to other alternatives for making conservation decisions, PVA's provide a rigorous methodology that can incorporate different types of data, uncertainties and natural variation, and provide outputs or predictions that are relevant to conservation goals (Akcakaya and Sjogren-Gulve 2000). PVA results also can incorporate uncertainties using sensitivity

analyses based on ranges of parameters, which gives a range of extinction risk estimates and other assessment end-points (Akcakaya 2000). This approach allows users to understand the effect of uncertain input, and to make decisions with full knowledge of those uncertainties.

For these reasons, a structured model approach was selected to address the following study objectives. First, develop a demographic and spatially structured model to be used as a conservation-planning tool in the Key deer HCP for Big Pine and No Name keys. Second, conduct a sensitivity analysis to identify model parameters that account for the greatest uncertainty in order to plan future field research. Finally, provide model users with an array of risk estimates including areas where development under different management scenarios can minimize impacts. Collectively, these objectives serve to aid in making conservation decisions for these 2 islands.

METHODS

Study Area

Big Pine and No Name keys are within the boundaries of the NKDR, Monroe County, and support the majority of the Key deer population (Chapters I and IV). All data described in this chapter were collected on these 2 islands. In addition, the scope of the PVA was limited to Big Pine and No Name keys due to the lack of information for other island deer populations. No deer dispersal was assumed between outer islands and the study area (this does not include dispersal between Big Pine and No Name). Six vegetation types were described by Silvy (1975) and Hardin (1974) and used in this study: pineland, hammock, developed, freshwater marsh, buttonwood, and mangrove (Chapters I and III).

Model Overview

A metapopulation model was developed for Florida Key deer with each island defined as a local population (Akcakaya 2000). Within each population, demographic changes were modeled using a spatially- and stage-structured, stochastic matrix model that allowed for annual changes in vital rates and incorporated impacts from regional catastrophes such as hurricanes. Only female Key deer were modeled in the PVA.

The program RAMAS Metapop (Akcakaya 1998) was used to develop the Key deer metapopulation model. Impacts due to spatial changes (loss of habitat) such as carrying-capacity estimates or increases in secondary impacts (highway mortality, Chapter II) were determined using ArcView Spatial Analyst (ESRI, Version 1.1). Future changes in Key deer populations

were simulated under different management or development scenarios. Proposed development scenarios for Big Pine and No Name keys included construction of new homes or businesses, and/or roadway construction or improvement. Model results were summarized in terms of risk of decline and compared risk estimates under alternative model assumptions and development scenarios.

Data Collection

Data used to estimate model parameters were derived from several sources. Population demographics were collected via radiotelemetry, survey or trend observations, and deer necropsies (Chapters II-VI). Telemetry, survey, and deer mortality data were entered into a GIS using ArcView (Version 3.2) and Microsoft Access (Version 97). Three spatial coverages were obtained for the development of the Key deer model – ownership, vegetation, and transportation. Ownership data were obtained from the Monroe County Tax office. Classifications used to describe ownership patterns were federal, state, county, private-developed, and private-undeveloped. The majority of publicly-owned land on Big Pine and No Name is largely conservation lands managed by the NKDR. Vegetation data were obtained from the Advanced Identification of Wetlands Project (MacAulay et al. 1994). Finally, a road coverage was obtained from Monroe County Property Appraisal office, Key West, Florida.

Demography

Survival.—Annual female survival estimates and variances were determined by age-class (3 classes - fawn, yearling, adult) using a known-fate model framework (Chapter II). Age categories used included fawns (assumed all deer were born on 1 April), yearlings (1-2 years old), and adults (> 2 years old). Fawn survival was overestimated because fawns < 4 months of age were under-represented in the sample (Chapter II). Fawn survival was fitted to equal the calculated eigenvalue from the matrix analysis. Furthermore, a variance estimate for fawn survival was determined by multiplying the coefficient of variation from the overestimated survival estimate to the fitted mean (Akcakaya 1998).

Fecundity.—Fecundity was estimated for yearlings and adults from necropsied deer. Hardin (1974) reported that deer maternity was 1.05 fawns per breeding female and year (yearlings and adults). Key deer less than 1 year were found not to be reproductively active (Hardin 1974, Folk and Klimstra 1991a). Previous studies (Klimstra et al. 1974, Hardin 1974) reported that Key deer fetal sex ratios are male biased (59% males). From these data, fecundity was determined for yearlings (F_y) and adults (F_a) by

$$F_y = R * M * S_y$$
$$F_a = R * M * S_a$$

where R is equal to the female fetal sex ratio, M is equal to maternity, and S_y and S_a are equal to yearling and adult survival, respectively (Chapters II and IV). Fecundity variances were determined as described by Burgman et al. (1993) where variance of the product of 2 values (1 and 2) was given by

$$var_{1x2} = var_1(mean_2)^2 + var_2(mean_1)^2 + 2mean_1 mean_1 mean_2 cov_{12}.$$

Mean, variance, and coefficient of variation estimates for maternities (1) and survivorships (2) were used in this formula.

Stage Structure.—Each female population was modeled with a stage-structure, stochastic matrix model with 3 stages (fawn, yearling, and adult). In developing this model, it was assumed (1) all reproduction occurred in a relatively short breeding season (1 April, Hardin 1974, "birth-pulse" population), (2) population was surveyed after each breeding season (post-reproductive survey), (3) all adults and yearlings breed (proportion of breeders determined by survival rate for adults and yearlings), and (4) the stage matrix was the same for both populations (Akcakaya 1991, Caswell 2000). With these assumptions, the stage matrix for the model was

$$\begin{bmatrix} & F_y & F_a \\ S_f & & \\ & S_y & S_a \end{bmatrix},$$

where S_f, S_y, and S_a are fawn, yearling, and adult survival, respectively, and F_y and F_a are yearling and adult maternity (fawns per doe), respectively.

Initial abundances for model simulations were determined (White and Garrot 1990) from mark-resight estimates for the month of April (Chapter IV). A stable age distribution was assumed for both populations, with 60 (16 fawns, 7 yearlings, and 37 adults) and 316 (83 fawns, 39 yearlings, and 194 adults) deer for Big Pine and No Name keys, respectively.

Density Dependence.—Density dependence was incorporated in the model using a contest-type density dependence (Beverton-Holt) with the assumption that populations grew at 10% when the N was low and 0% growth when $N = K$ (Akcakaya 1991). Population growth rate (R) at time step t was determined by

$$R(t) = \frac{R_{max} * K}{R_{max} * N(t) - N(t) + K} ,$$

where R_{max} is equal to maximal growth rate, K is equal to population carrying-capacity, and N is equal to the current population size (Chapter IV). Maximal growth rates (1.05-1.10) were estimated from survey data (1990-99).

Dispersal.—Dispersal is an important mechanism in the persistence of a metapopulation. Annual dispersal rates between Big Pine and No Name keys were estimated from radio-collared deer (Chapter V).

Environmental and Demographic Stochasticity.—Natural environments are known to fluctuate, causing changes in the population dynamics (survival, fecundity, abundances) of species (Akcakaya 1991). A realistic attempt to model the population dynamics of a species should account for this fact. Stochasticity incorporated in the Key deer model included (1) environmental fluctuations, (2) demographic variability, and (3) catastrophes. Environmental stochasticity was incorporated by sampling vital rates from random (lognormal) distributions with means taken from a mean stage matrix and standard deviations taken from a "standard deviation matrix" (Akcakaya 1991). During model simulations, samples from these matrices were taken for each time step (1 year). Demographic stochasticity was incorporated in model simulations by sampling (1) the number of survivors from a binomial distribution, (2) the number of offspring from a Poisson distribution, and (3) the number of individuals dispersing between populations from a binomial distribution (Akcakaya 1991). With stochasticity incorporated in the model, repeated simulations could be used to generate a range of predictions.

Hurricanes have been hypothesized to have a negative impact on Key deer (Folk 1991). In the model, 2 catastrophe types were included: catastrophe 1 (Category 3-4 hurricane), and catastrophe 2 (Category 4-5 hurricane). It was assumed hurricanes would impact population abundances regionally (all populations would be impacted). Due to the uncertainty of storm impacts on Key deer (Chapter VI), storm occurrence probabilities and anticipated impacts on abundances were varied (low, medium, and high). Hurricane probability information was

obtained from the National Hurricane Center in Miami, Florida. The model HURISK was used to estimate the probability of the storm center striking within 25 nautical miles of Big Pine and No Name keys (Neumann 1991). Hurricane impacts modeled in the PVA were greater than previous PVA's (Seal and Lacy 1990).

Spatial Data

Spatial information, such as ownership and vegetation patterns, were important in identifying areas that could be developed in the future and projected impacts from such development. Urban development was assumed to result in (1) a change in carrying capacity, and (2) an increase in mortality due to secondary impacts (e.g., traffic increases, entanglement in fences) in the Key deer population (Chapters II-III). Changes in these 2 parameters were estimated using ArcView Spatial Analyst (Version 2). All coverages described in this study (i.e., ownership, vegetation coverages) were converted to raster or grid-based layers at a 10-m resolution. These coverages, in addition to other demographic data, were used to generate 4 grid layers important in model implementation: (1) weighting factor grid, (2) carrying-capacity grid, (3) harvest grid, and (4) PUV grid. Descriptions of each of these grids will be presented.

Weighting Factor Grid.—It was assumed that development in higher quality deer habitat would have a greater impact on the deer population. For example, a hectare of habitat in the northern portion of Big Pine Key might be more valuable than a hectare in the southern half of the island due to differences in traffic and deer density (Chapters II and IV). Therefore, a method to identify higher quality deer habitat was necessary. Six grids were averaged and used to generate a weighting factor grid in which cell values gave an estimate of the overall habitat value to Key deer. Cell values for all 6 grids ranged from 0-2 with a value of 2 equal to higher quality deer habitat, hence, greater impact of potential development. The 6 grid layers used were as follows:

1. *House density*. It was assumed that development in areas with a high house density would result in lower deer impact. The ownership layer linked to the county tax roll was queried, and a polygon with a centroid was generated showing the placement of houses for Big Pine Key. A 95% probability polygon was generated from the house point locations using a kernel method estimator (Worton 1989, Hooge and Eichenlaub 1997). All of No Name Key was assumed to have a cell-value of 2 due to the small number of houses on the island (42 homes on entire island). Assigned cell values were 0 = water, 1 = high house density, and 2 = low house density.

2. *Deer corridors*. Urban development in corridor areas was assumed to result in greater deer impact. Two deer corridors were identified as important to Key deer movements. The first corridor joins north and south Big Pine Key and was recommended as part of a study conducted in 1998 (Grist et al. 1999). The second corridor joins Big Pine and No Name via the Tropical Bay and Doctors Arm area. Assigned cell values were 0 = water, 1 = no corridor, and 2 = corridor area.

3. *Patch quality*. A patch quality grid was generated by taking the vegetation grid and conducting a nearest neighbor analysis using a 100-m^2 grid (ArcView Spatial Analyst, Version 2). All cells that fell within the 100-m^2 "moving window" were averaged and the center cell was re-assigned that value. Values ranged from 0-2, with 2 the most preferred deer habitat from radio-telemetry locations (Chapter III). Assigned cell values were 0 = water, 0.33 = mangrove, 0.67 = buttonwood, 1.00 = freshwater marsh, 1.33 = developed, 1.67 = pineland, and 2.00 = hammock. The assumption with this grid layer was that development in higher quality deer habitat would result in a greater impact to the deer.

4. *Deer density*. It was assumed that development in areas with high deer density would result in greater impact to the deer population. Survey data digitized along a standardized route (1998-00, Chapter IV) were used to create a point polygon. A 95% probability polygon was generated from deer locations using a kernel method estimator (Worton 1989, Hooge and Eichenlaub 1999). All of No Name Key was assumed to have a cell-value of 2 due to the high deer density on the island (Chapter IV). Assigned cell values were 0 = water, 1 = low deer density, and 2 = high deer density.

5. *Distance from US 1*. Previous studies have documented that highway mortality accounts for the majority of Key deer losses (Hardin 1974, Folk 1991). Furthermore, recent studies have documented nearly 50% of all highway mortality occurs on US 1 (Chapter II). In this model, it was assumed that development farther away from US 1 would have a greater impact on the deer population because of an increase in overall daily trips (most businesses are along US 1 corridor). The buffering feature in ArcView (Version 3.2) was used to generate buffer zones around the US 1 corridor at 2,000-m increments. Assigned cell values were 0 = water, 0.5 = < 2,000 m, 1 = 2,000-4,000 m, 1.5 = 4,000-6,000 m, and 2 = > 6,000 m.

6. *Water Barriers.* Many residential areas or subdivisions on Big Pine and No Name are bisected with canals for water access (Folk 1991). It has been observed that these areas restrict deer movement and result in deer mortality through drowning (Folk 1991, Chapter II). Urban development in areas surrounded by canals (lower deer use areas) were identified and mapped. It was assumed that development in areas surrounded by canals would have a lower impact because of the small likelihood that deer would use these areas. Assigned cell values were 0 = water, 1 = low deer use, 2 = high deer use.

Carrying-Capacity Grid.—Hypothesized carrying capacities were determined for each cell in the grid based on each cell's vegetation type. Cell values were calculated by multiplying the estimate of the overall deer density on No Name Key (on a per cell basis) by the habitat selection ratio associated with the cell's vegetation type, as determined from radio telemetry data (Chapter III). The overall deer density estimate from No Name Key was chosen because survey data and herd health indices suggest the island's deer population is at or near carrying capacity (Chapter III, Nettles et al. 2001). Resulting cell values were then normalized so that the sum of all cell values was equal to the sum prior to adjustment with the selection ratio (percent increase multiplied to all cells). Thus, the estimated carrying capacity (K) for each island is represented by the function

$$K = 0.045 \sum(MG_a) + 0.079 \sum(BW_a) + 0.113 \sum(FM_a) 0.135 \sum(UA_a) + 0.204 \sum(PL_a) + 0.231 \sum(HM_a)$$

where MG_a is equal to mangrove area (ha), BW_a is equal to buttonwood area (ha), FM_a is equal to freshwater marsh area (ha), UA_a is equal to urban area (ha), PL_a is equal to pineland area (ha), and HM_a is equal to hammock area (ha). This grid allowed changes in carrying capacity to be calculated under different development scenarios by simply summing all grid values for each island. For example, if development occurred in 10 ha of pineland, those areas would be reclassified to urban, allowing an estimate of carrying capacity to be re-calculated and used in the model. It was assumed that development would render the entire parcel unavailable to deer due to loss of habitat (house footprint) and possible fencing of remaining area.

Harvest Grid.—Secondary impacts due to development (e.g., traffic increases, entanglement in fences, Chapter II) were modeled using the harvest function in RAMAS Metapop (Akcakaya 1991). RAMAS Metapop allows users to determine the spatial extent and quantity (number or proportion of individuals) of animals to be "harvested" in a metapopulation. Human-related mortality can be viewed as a form of "harvest" in modeling the population dynamics of the Key deer herd. For example, construction of 100 houses would result in an increase of traffic, increasing the probability of deer dying. Data suggest that human-related mortality, particularly highway mortality, is density-dependent (Chapter II), therefore, an increase in development could be modeled as a form of harvest affecting a proportion of individuals on Big Pine Key. Preliminary spatial analyses suggested the majority of development would occur on Big Pine, thus, impacts were limited in model simulations to this island. Development in the model took 2 forms: (1) transportation improvements and (2) development of new homes or businesses. A review of each of these forms of development is discussed below:

1. *Road Improvements.* US 1 traffic problems have long plagued Big Pine and No Name Key residents and resulted in a building moratorium in 1995 (Chapter I, Calvo 1996). A cross-island road allowing residents to avoid access to US 1 has been suggested as a corrective measure (C. Owens, FDOT, personal communication). Lyttons Way on Big Pine Key is an existing unimproved road that parallels US 1, however, residents desire the road be improved or paved, which is expected to increase deer mortality. The percent highway mortality (USFWS deer mortality data, 1990-99) on Watson Boulevard, an improved road that is parallel to Lyttons Way, was determined and used to estimate expected mortality on Lyttons Way. Expected percent mortality increase was adjusted based on the length of the proposed development. It was assumed a mortality increase of 2.38% would occur if Lyttons Way were to be paved.

2. *Development.* It was assumed that additional development would increase deer mortality (Chapter II). The county tax roll was queried to determine the number of houses on these 2 islands. The USFWS mortality database also was queried to determine the average percent human-related deer mortality (highway mortality, dogs, entanglement) that occurred in the last 5 years (deer mortality divided by estimated deer population, 1996-00, Chapter II). With this information, the proportion of deer that died due to human-caused mortality (8%) was estimated and divided by the average number of houses. The end result was an estimate of the percent deer mortality per house that was converted to a per cell basis (0.0205% per ha). Assuming development in higher quality deer habitat and in areas with greater deer densities would result in an overall greater impact to the deer, cell values were multiplied by the weighting factor grid. All cell values were then normalized (Sum of cell values were equal to the sum of cell values prior to adjustment with weighting factor grid. Percent increase in sum multiplied to all cell values). An increase in mortality due to development could then be estimated using the harvest grid. Thus, estimated mortality increase (H) for each island is represented by the function

$$H = HG_a$$

where HG_a is the sum of cell values. This grid allowed the estimated mortality increases to be calculated under different development scenarios (areas that were reclassified) by simply summing all grid values for each island.

PUV Grid.—In use of the model, it was assumed that all development was to occur on privately owned, upland (no development in wetlands), vacant (PUV) lots. The sum of all PUV lands is the total area where development can potentially occur on Big Pine and No Name keys. PUV areas were identified and classified using the vegetation and ownership coverages. By assuming that development occurs in areas of lowest habitat value, assigned cell values were 1 = PUV urban, 2 = PUV pineland, and 3 = PUV hammock. Multiplying the PUV grid and weighting factor grid generated a weighted PUV grid, which ranked PUV land by habitat value. It is important to note that, due to the spatial structure of the model in calculating changes in deer carrying capacity and increases in deer mortality for different scenarios, varying amounts of development in worse to best habitat could be compared. In other words, users of the model might decide that rather than building 200 houses in the worse deer habitat they might want to

build 100 houses in better habitat. For this example, risks for these 2 scenarios might in fact be similar due to the spatial nature of the model.

Model Use

The analysis of the Key deer metapopulation consisted of a series of simulations. Evaluation of each scenario consisted of 10,000 replications for 100 time steps (years). To illustrate the use of the Key deer model, 5 development scenarios were evaluated:

1. Scenario 0 = no change
2. Scenario 1 = road improvement
3. Scenario 2 = road improvement + 100 houses
4. Scenario 3 = road improvement + 300 houses
5. Scenario 4 = road improvement + 500 houses

where road improvement was defined as the paving of Lyttons Way and development of houses referred to development in areas with the lowest PUV value. To analyze the sensitivity of model results to parameters, 3 simulations of each parameter were run using the low, medium, and upper estimates of that parameter and the medium estimates of all other parameters (Tables 7.1-7.2). Eight parameters were varied, resulting in 17 models per scenario.

Two measures of evaluating the viability of the Key deer metapopulation were used: (1) risk of metapopulation going extinct in 50 and 100 years, and (2) risk of falling below metapopulation threshold (25, 50, and 100 individuals) in 50 and 100 years. Furthermore, the level of development by scenario was summarized using a zoning map of the 2 islands.

Table 7.1. Suite of 17 models for each management scenario in the population viability analysis of Florida Key deer.

Model name [a]	Model description
0Medium	Scenario 0, best estimates used, no parameters varied
0Cat1MH	Scenario 0, % survival, catastrophe 1 (Category 3-4 hurricane), high
0Cat1ML	Scenario 0, % survival, catastrophe 1 (Category 3-4 hurricane), low
0Cat1PH	Scenario 0, probability, catastrophe 1 (Category 3-4 hurricane), high
0Cat1PL	Scenario 0, probability, catastrophe 1 (Category 3-4 hurricane), low
0Cat2MH	Scenario 0, % survival, catastrophe 2 (Category 4-5 hurricane), high
0Cat2ML	Scenario 0, % survival, catastrophe 2 (Category 4-5 hurricane), low
0Cat2PH	Scenario 0, probability, catastrophe 2 (Category 4-5 hurricane), high
0Cat2PL	Scenario 0, probability, catastrophe 2 (Category 4-5 hurricane), low
0DispH	Scenario 0, dispersal rate between local populations, high
0DispL	Scenario 0, dispersal rate between local populations, low
0KH	Scenario 0, carrying-capacity (+10%), high
0KL	Scenario 0, carrying-capacity (-10%), low
0RmH	Scenario 0, *Rmax* estimate, high
0RmL	Scenario 0, *Rmax* estimate, low
0SDH	Scenario 0, fecundity standard deviation (+10% CV), high
0SDL	Scenario 0, fecundity standard deviation (-10% CV), low

[a] Model descriptions similar to other scenarios with the exception of the first number, which refers to the scenario number. For example, model name 1CatMH = Scenario 1, % survival, catastrophe 1 (Category 3-4 hurricane), high (compare to 0CatMH, note scenario number is only difference).

Table 7.2. Low, medium, and high parameter estimates used in population viability analysis for Key deer on BPK and NNK.

Parameter	Low	Medium	High
Survival	Not varied	*Age = mean (SD)* Fawn = 0.470 (0.061) Yearling = 0.824 (0.071) Adult = 0.840 (0.030)	Not varied
Fecundity	Not varied	*Age = maternity* Fawn = 0.000 Yearling = 0.3548 Adult = 0.3625	Not varied
Fecundity SD	*Age = fecundity SD* Yearling = 0.1371 Adult = 0.1217 High (30% CV)	*Age = fecundity SD* Yearling = 0.1016 Adult = 0.0855 Average (20% CV)	*Age = fecundity SD* Yearling = 0.0662 Adult = 0.0492 Low (10% CV)
Rmax	1.01	1.05	1.10
Carrying-capacity [a] (±10% average)	54 (NNK) 299 (BPK = S0-S1) 297 (BPK = S2) 293 (BPK = S3) 290 (BPK = S4)	60 (NNK) 332 (BPK = S0-S1) 330 (BPK = S2) 326 (BPK = S3) 322 (BPK = S4)	66 (NNK) 365 (BPK = S0-S1) 363 (BPK = S2) 359 (BPK = S3) 354 (BPK = S4)
Catastrophe 1 (*P*)	0.03	0.02 [b]	0.01
Catastrophe 1 (Impacts)	*Age = % survival* Fawn = 0.40 Yearling = 0.65 Adult = 0.75	*Age = % survival* Fawn = 0.50 Yearling = 0.75 Adult = 0.85	*Age = % survival* Fawn = 0.60 Yearling = 0.85 Adult = 0.95

Table 7.2. Continued.

Parameter	Low	Medium	High
Catastrophe 2 (*P*)	0.02	0.01 [b]	0.005
Catastrophe 2 (Impacts)	*Age = % survival* Fawn = 0.00 Yearling = 0.10 Adult = 0.40	*Age = % survival* Fawn = 0.10 Yearling = 0.20 Adult = 0.50	*Age = % survival* Fawn = 0.20 Yearling = 0.30 Adult = 0.60
Dispersal	0% Low dispersal	3.50% Average dispersal	5.25% High dispersal

[a] Carrying-capacity changed for each management scenario depending on expected habitat loss. Changes applied to BPK only. Management scenarios: S0 (Scenario 0) = no change, S1 (Scenario 1)= road improvement, S2 (Scenario 2) = road improvement + 100 houses, S3 (Scenario 3) = road improvement + 300 houses, and S4 (Scenario 4) = road improvement + 500 houses.

[b] Storm probability (mean return period) of occurrence (catastrophe 1 = Category 3-4 hurricane, catastrophe 2 = Category 4-5 hurricane). Data from the National Weather Service, 2000.

RESULTS

A model was developed to serve as a tool in the conservation of Key deer for Big Pine and No Name keys (Figs. 7.1-7.11). A summary of model parameters used in the model, including low and upper parameter estimates, is outlined (Table 7.2). With most parameter combinations, the model predicted a low risk of decline for the Key deer population (Tables 7.3-7.7). For example, the risk of the deer metapopulation falling below 25 individuals in 50 years ranged from 0.5-5.2% depending on the management scenario (5.2% is risk estimate for scenario 4, Tables 7.5-7.6, Fig. 7.9). The level of risk for the Key deer, however, needs to be evaluated in light of what is an acceptable level of risk. Criteria to be used in determining what is acceptable is a societal issue and outside the scope of a PVA (Akcakaya and Sjogren-Gulve 2000). Differences in risk estimates also illustrate the importance of selecting the appropriate "level of risk" in a PVA (Table 7.6). In order to assist decision-makers in determining acceptable levels of risk, several tables and figures were constructed (Tables 7.3-7.6, Fig. 7.9) to summarize levels of risk for different scenarios, metapopulation thresholds (25, 50, and 100 individuals), and simulation timelines (50 and 100 years). In summarizing the amount of development (management scenarios S2-S4) by zones (Figs. 7.6, 7.10-7.11), the majority of development would occur in region 5 and 6, which have been avoided by current conservation land acquisitions (P. Frank, USFWS, personal communication).

Model results were most sensitive to the deer's maximal growth rate estimate (R_{max}), and annual probabilities and hypothesized impacts of severe hurricanes (Category 4-5, Table 7.7, Fig. 7.7). Model results were not sensitive to dispersal, fecundity SD, and the probability and hypothesized impacts of moderate hurricanes (Category 3-5, Table 7.7, Fig. 7.7, Chapter VI).

Table 7.3. Risk estimates [a], final population sizes, and additional deer killed under different management scenarios for 85 models. Extinction threshold of 100 individuals.

	Risk [a]			Population size		Population size					
	R_0	R_{100}	R_{100}	in 100 years		in 50 years		Additional deer killed			
Model [b]	*(100)*	*(100)*	*(50)*	0	SD	0	SD	0	SD	Min.	Max.
0Medium	0.001	0.281	0.121	264	115	288	113	0	0	0	0
0Cat1MH	0.000	0.233	0.102	284	115	301	114	0	0	0	0
0Cat1ML	0.001	0.358	0.163	245	117	271	116	0	0	0	0
0Cat1PH	0.001	0.235	0.101	283	115	302	114	0	0	0	0
0Cat1PL	0.001	0.323	0.152	249	112	271	112	0	0	0	0
0Cat2MH	0.000	0.155	0.060	283	106	299	104	0	0	0	0
0Cat2ML	0.005	0.459	0.236	244	127	274	124	0	0	0	0
0Cat2PH	0.000	0.135	0.057	299	105	312	104	0	0	0	0
0Cat2PL	0.008	0.559	0.290	202	120	237	122	0	0	0	0
0DispH	0.000	0.274	0.121	267	114	288	113	0	0	0	0
0DispL	0.000	0.294	0.127	263	113	286	113	0	0	0	0
0KH	0.000	0.238	0.100	292	127	313	123	0	0	0	0
0KL	0.001	0.332	0.142	242	106	264	104	0	0	0	0
0RmH	0.000	0.115	0.055	327	90	328	91	0	0	0	0
0RmL	0.026	0.586	0.270	153	135	235	149	0	0	0	0
0SDH	0.000	0.257	0.114	269	111	288	110	0	0	0	0
0SDL	0.001	0.312	0.141	260	119	283	120	0	0	0	0
1Medium	0.004	0.658	0.324	133	75	174	79	393	113	40	766
1Cat1MH	0.003	0.597	0.284	146	77	184	80	414	113	44	804
1Cat1ML	0.006	0.738	0.385	120	74	164	80	372	115	45	794
1Cat1PH	0.002	0.610	0.288	145	77	185	81	413	114	14	829
1Cat1PL	0.005	0.716	0.356	121	72	164	77	373	111	46	740
1Cat2MH	0.000	0.589	0.246	145	71	183	74	409	104	70	804
1Cat2ML	0.015	0.716	0.395	122	79	166	85	376	122	7	807
1Cat2PH	0.000	0.490	0.194	157	72	194	74	430	102	74	802
1Cat2PL	0.025	0.851	0.521	94	71	144	82	330	119	20	781
1DispH	0.004	0.665	0.321	131	76	173	79	395	115	29	799
1DispL	0.002	0.639	0.308	141	73	178	79	364	108	36	838
1KH	0.003	0.614	0.293	145	82	188	86	419	122	39	869

Table 7.3. Continued.

	Risk [a]			Population size in 100 years		Population size in 50 years		Additional deer killed			
Model [b]	R_0 (100)	R_{100} (100)	R_{100} (50)	0	SD	0	SD	0	SD	Min.	Max.
1KL	0.005	0.719	0.355	121	69	162	73	366	104	14	733
1RmH	0.000	0.317	0.141	241	77	247	76	534	85	120	788
1RmL	0.116	0.975	0.640	35	36	101	68	252	105	18	905
1SDH	0.003	0.643	0.304	134	73	176	76	396	110	57	891
1SDL	0.003	0.694	0.345	131	78	174	83	389	115	48	803
2Medium	0.004	0.712	0.354	122	71	164	75	409	117	46	837
2Cat1MH	0.003	0.643	0.308	135	73	175	76	432	118	8	950
2Cat1ML	0.007	0.774	0.406	110	70	157	78	390	121	40	825
2Cat1PH	0.003	0.652	0.318	135	74	174	78	431	120	52	808
2Cat1PL	0.007	0.765	0.392	111	67	155	73	389	115	25	830
2Cat2MH	0.000	0.654	0.284	133	67	172	71	427	108	76	817
2Cat2ML	0.018	0.742	0.418	111	74	156	81	392	129	15	828
2Cat2PH	0.001	0.552	0.217	145	69	183	71	450	106	77	871
2Cat2PL	0.030	0.877	0.554	85	66	133	79	343	127	17	780
2DispH	0.006	0.723	0.362	118	70	163	76	412	119	54	885
2DispL	0.004	0.690	0.341	130	69	168	75	377	111	36	776
2KH	0.004	0.669	0.328	131	75	175	81	434	127	28	887
2KL	0.005	0.752	0.388	114	65	154	70	384	108	41	735
2RmH	0.000	0.345	0.157	232	75	239	75	565	90	119	875
2RmL	0.125	0.982	0.675	32	32	96	64	265	109	13	823
2SDH	0.003	0.682	0.329	123	68	166	73	414	113	60	816
2SDL	0.004	0.733	0.373	121	74	165	80	408	122	21	881
3Medium	0.008	0.796	0.423	100	62	145	69	444	128	58	907
3Cat1MH	0.005	0.744	0.370	109	63	155	71	465	130	42	914
3Cat1ML	0.012	0.863	0.492	87	59	134	69	417	130	43	926
3Cat1PH	0.005	0.748	0.370	111	64	155	70	466	131	48	913
3Cat1PL	0.009	0.852	0.476	90	59	135	67	419	125	54	969
3Cat2MH	0.001	0.768	0.356	109	60	152	65	461	119	107	1028
3Cat2ML	0.024	0.815	0.461	90	64	138	73	425	139	27	973
3Cat2PH	0.002	0.731	0.333	115	63	158	70	477	127	79	951

Table 7.3. Continued.

	Risk [a]			Population size		Population size					
	R_0	R_{100}	R_{100}	in 100 years		in 50 years		Additional deer killed			
Model [b]	*(100)*	*(100)*	*(50)*	0	SD	0	SD	0	SD	Min.	Max.
3Cat2PL	0.047	0.923	0.627	68	56	115	70	369	135	19	878
3DispH	0.009	0.807	0.423	96	62	144	69	448	132	44	941
3DispL	0.005	0.779	0.409	110	60	150	69	399	120	55	829
3KH	0.006	0.775	0.397	105	65	153	74	467	138	27	961
3KL	0.009	0.838	0.457	93	58	136	65	416	120	45	884
3RmH	0.000	0.422	0.203	211	72	219	72	628	105	188	944
3RmL	0.176	0.996	0.783	22	23	78	54	280	108	14	910
3SDH	0.007	0.776	0.401	101	60	146	67	446	125	45	927
3SDL	0.007	0.827	0.451	99	64	144	72	437	132	53	922
4Medium	0.014	0.892	0.514	76	52	125	62	467	138	77	1022
4Cat1MH	0.010	0.851	0.458	86	55	133	64	493	140	43	987
4Cat1ML	0.022	0.926	0.584	68	50	116	62	443	139	70	990
4Cat1PH	0.009	0.852	0.462	86	55	133	64	493	141	83	1038
4Cat1PL	0.018	0.923	0.564	69	49	116	60	444	134	60	924
4Cat2MH	0.004	0.880	0.477	83	51	130	59	484	129	65	1077
4Cat2ML	0.039	0.901	0.537	70	53	119	67	449	150	19	999
4Cat2PH	0.002	0.829	0.391	94	52	139	59	511	129	97	998
4Cat2PL	0.063	0.959	0.673	52	46	101	63	398	143	34	907
4DispH	0.015	0.898	0.522	73	52	122	62	471	143	42	1057
4DispL	0.010	0.872	0.478	91	52	130	60	415	124	61	890
4KH	0.011	0.870	0.490	81	55	131	66	488	148	59	1056
4KL	0.051	0.994	0.793	40	32	83	45	471	137	51	1065
4RmH	0.000	0.504	0.251	189	68	200	68	690	120	160	1063
4RmL	0.248	0.999	0.875	16	17	63	45	296	110	32	827
4SDH	0.011	0.878	0.486	78	50	125	60	470	135	48	904
4SDL	0.014	0.909	0.554	76	54	123	65	464	142	42	1036

[a] R_0 *(100)* – risk of extinction in 100 years.

R_{100}*(100)* – risk of population falling below 100 individuals in 100 years.

R_{100}*(50)* – risk of population falling below 100 individuals in 50 years.

[b] For model descriptions, see Table 7.1.

Table 7.4. Risk estimates [a], final population sizes, and additional deer killed under different management scenarios for 85 models. Extinction threshold of 50 individuals.

	Risk [a]			Population size		Population size					
	R_0	R_{50}	R_{50}	in 100 years		in 50 years		Additional deer killed			
Model [b]	*(100)*	*(100)*	*(50)*	0	SD	0	SD	0	SD	Min.	Max.
0Medium	0.001	0.070	0.023	265	114	285	113	0	0	0	0
0Cat1MH	0.000	0.055	0.019	284	116	303	113	0	0	0	0
0Cat1ML	0.001	0.100	0.031	246	117	271	117	0	0	0	0
0Cat1PH	0.000	0.055	0.019	285	117	302	114	0	0	0	0
0Cat1PL	0.001	0.090	0.029	247	112	272	113	0	0	0	0
0Cat2MH	0.000	0.018	0.005	284	106	300	105	0	0	0	0
0Cat2ML	0.005	0.174	0.069	243	126	271	125	0	0	0	0
0Cat2PH	0.000	0.020	0.006	298	105	313	103	0	0	0	0
0Cat2PL	0.009	0.247	0.095	201	121	237	123	0	0	0	0
0DispH	0.001	0.072	0.023	265	115	286	113	0	0	0	0
0DispL	0.001	0.071	0.024	265	114	287	113	0	0	0	0
0KH	0.000	0.059	0.018	292	127	314	123	0	0	0	0
0KL	0.001	0.086	0.028	241	106	265	103	0	0	0	0
0RmH	0.000	0.010	0.005	326	91	327	90	0	0	0	0
0RmL	0.027	0.328	0.088	154	137	235	148	0	0	0	0
0SDH	0.000	0.067	0.023	268	112	288	109	0	0	0	0
0SDL	0.001	0.078	0.028	260	119	283	119	0	0	0	0
1Medium	0.004	0.286	0.086	133	74	174	79	391	111	23	753
1Cat1MH	0.002	0.231	0.069	146	77	187	80	416	114	19	782
1Cat1ML	0.006	0.360	0.113	121	74	164	80	372	115	50	792
1Cat1PH	0.002	0.244	0.070	146	77	185	81	414	113	54	786
1Cat1PL	0.004	0.337	0.101	121	72	165	78	373	111	27	762
1Cat2MH	0.001	0.187	0.042	144	72	182	75	408	105	60	752
1Cat2ML	0.014	0.410	0.154	121	78	166	85	376	122	9	831
1Cat2PH	0.000	0.138	0.032	160	73	193	75	431	102	68	800
1Cat2PL	0.027	0.560	0.225	93	71	141	82	327	119	35	753
1DispH	0.004	0.296	0.085	131	75	174	79	395	114	38	831
1DispL	0.003	0.271	0.079	139	73	178	78	362	107	46	851

Table 7.4. Continued.

	Risk [a]			Population size in 100 years		Population size in 50 years		Additional deer killed			
Model [b]	R_0 (100)	R_{50} (100)	R_{50} (50)	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Min.	Max.
1KH	0.002	0.252	0.076	146	81	187	85	418	121	66	841
1KL	0.004	0.325	0.098	121	69	160	72	365	104	49	714
1RmH	0.000	0.049	0.018	241	76	246	76	534	85	152	776
1RmL	0.112	0.842	0.298	36	36	103	68	253	105	17	795
1SDH	0.003	0.260	0.074	136	73	176	76	396	110	14	736
1SDL	0.005	0.319	0.098	131	78	173	82	388	117	50	797
2Medium	0.005	0.322	0.096	123	71	165	75	410	118	60	846
2Cat1MH	0.002	0.266	0.074	135	73	175	75	432	117	35	819
2Cat1ML	0.008	0.401	0.128	110	69	156	77	389	121	33	825
2Cat1PH	0.003	0.264	0.080	136	74	176	78	433	120	43	898
2Cat1PL	0.006	0.370	0.111	110	66	155	74	390	116	43	802
2Cat2MH	0.000	0.207	0.046	133	67	172	71	426	108	73	825
2Cat2ML	0.019	0.452	0.173	110	74	156	83	391	130	13	820
2Cat2PH	0.001	0.162	0.036	146	69	185	71	451	107	75	811
2Cat2PL	0.033	0.585	0.231	85	66	134	79	343	125	19	772
2DispH	0.004	0.328	0.098	120	71	164	77	414	120	62	858
2DispL	0.005	0.296	0.087	130	68	169	75	376	110	20	764
2KH	0.004	0.299	0.087	129	75	173	81	432	125	54	884
2KL	0.004	0.349	0.113	114	66	155	72	385	109	10	787
2RmH	0.000	0.053	0.020	232	75	239	75	565	89	218	827
2RmL	0.136	0.873	0.337	31	32	94	63	261	106	11	809
2SDH	0.004	0.301	0.090	124	69	166	74	413	116	25	853
2SDL	0.006	0.342	0.106	120	73	163	80	405	121	44	829
3Medium	0.007	0.406	0.119	101	62	146	69	445	129	55	988
3Cat1MH	0.005	0.345	0.099	109	63	153	70	463	130	62	911
3Cat1ML	0.011	0.499	0.159	88	60	136	70	419	131	67	871
3Cat1PH	0.004	0.346	0.104	110	64	155	72	468	132	65	950
3Cat1PL	0.010	0.470	0.141	90	58	137	68	420	127	24	895
3Cat2MH	0.002	0.313	0.066	109	60	152	65	461	120	85	924
3Cat2ML	0.027	0.513	0.197	91	64	138	74	424	140	42	912

Table 7.4. Continued.

	Risk [a]			Population size in 100 years		Population size in 50 years		Additional deer killed			
Model [b]	R_0 (100)	R_{50} (100)	R_{50} (50)	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Min.	Max.
3Cat2PH	0.003	0.294	0.068	113	62	157	68	474	125	58	961
3Cat2PL	0.041	0.664	0.278	69	57	117	71	373	135	23	985
3DispH	0.010	0.427	0.122	95	61	143	69	443	133	48	919
3DispL	0.006	0.366	0.106	109	60	151	68	402	120	41	859
3KH	0.007	0.380	0.106	106	66	153	74	468	137	61	944
3KL	0.008	0.447	0.138	92	57	136	64	414	119	44	854
3RmH	0.000	0.074	0.026	211	72	220	72	630	104	166	954
3RmL	0.177	0.936	0.413	22	24	78	54	281	110	30	854
3SDH	0.006	0.384	0.111	102	60	146	67	446	125	64	849
3SDL	0.010	0.435	0.138	98	64	145	73	438	134	41	981
4Medium	0.013	0.535	0.172	77	52	124	61	467	138	50	1037
4Cat1MH	0.009	0.460	0.137	86	54	133	63	493	139	60	972
4Cat1ML	0.022	0.624	0.215	68	50	116	62	442	139	35	1017
4Cat1PH	0.009	0.475	0.138	86	55	133	63	492	141	28	1017
4Cat1PL	0.018	0.597	0.196	69	49	117	61	446	136	14	968
4Cat2MH	0.004	0.459	0.106	83	50	130	58	483	127	111	989
4Cat2ML	0.038	0.609	0.246	70	53	118	65	450	148	45	1053
4Cat2PH	0.003	0.369	0.085	93	53	139	59	510	128	73	999
4Cat2PL	0.070	0.761	0.337	51	46	100	64	394	145	34	974
4DispH	0.018	0.565	0.177	72	51	122	61	468	141	43	1019
4DispL	0.009	0.472	0.148	90	51	130	61	414	124	56	882
4KH	0.011	0.514	0.152	81	55	130	65	490	146	49	1039
4KL	0.051	0.837	0.340	41	33	84	45	472	138	78	1042
4RmH	0.000	0.106	0.039	187	67	200	67	688	118	186	1038
4RmL	0.244	0.978	0.521	16	17	63	45	296	109	28	841
4SDH	0.012	0.509	0.152	78	50	125	60	470	133	52	961
4SDL	0.016	0.559	0.177	76	53	124	65	464	142	28	1106

[a] R_0 *(100)* – risk of extinction in 100 years.

R_{50} *(100)* – risk of population falling below 50 individuals in 100 years.

R_{50} *(50)* – risk of population falling below 50 individuals in 50 years.

[b] For model descriptions, see Table 7.1.

Table 7.5. Risk estimates [a], final population sizes, and additional deer killed under different management scenarios for 85 models. Extinction threshold of 25 individuals.

	Risk [a]			Population size		Population size					
	R_0	R_{25}	R_{25}	in 100 years		in 50 years		Additional deer killed			
Model [b]	*(100)*	*(100)*	*(50)*	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Min.	Max.
0Medium	0.001	0.020	0.005	264	117	287	114	0	0	0	0
0Cat1MH	0.000	0.014	0.003	281	116	302	114	0	0	0	0
0Cat1ML	0.002	0.032	0.008	244	116	270	116	0	0	0	0
0Cat1PH	0.000	0.011	0.003	284	116	302	114	0	0	0	0
0Cat1PL	0.001	0.023	0.006	247	112	272	112	0	0	0	0
0Cat2MH	0.000	0.003	0.001	281	106	301	105	0	0	0	0
0Cat2ML	0.004	0.065	0.020	247	126	273	125	0	0	0	0
0Cat2PH	0.000	0.003	0.001	300	105	313	102	0	0	0	0
0Cat2PL	0.008	0.103	0.029	201	120	238	122	0	0	0	0
0DispH	0.001	0.020	0.004	266	116	287	113	0	0	0	0
0DispL	0.001	0.016	0.003	265	113	285	112	0	0	0	0
0KH	0.000	0.017	0.005	290	125	309	124	0	0	0	0
0KL	0.001	0.020	0.005	241	106	265	104	0	0	0	0
0RmH	0.000	0.001	0.000	326	89	330	90	0	0	0	0
0RmL	0.026	0.119	0.003	155	134	234	147	0	0	0	0
0SDH	0.000	0.014	0.003	268	111	289	110	0	0	0	0
0SDL	0.001	0.020	0.006	262	121	284	117	0	0	0	0
1Medium	0.004	0.103	0.018	135	75	175	79	394	112	21	781
1Cat1MH	0.002	0.078	0.014	146	76	186	80	415	111	42	822
1Cat1ML	0.007	0.148	0.028	120	73	163	80	371	114	41	751
1Cat1PH	0.003	0.086	0.017	145	78	185	81	414	114	60	800
1Cat1PL	0.004	0.122	0.020	123	71	166	78	376	110	32	754
1Cat2MH	0.000	0.046	0.004	144	71	183	74	409	103	70	752
1Cat2ML	0.016	0.196	0.053	122	79	167	86	376	124	21	855
1Cat2PH	0.000	0.033	0.005	158	72	195	74	432	102	75	819
1Cat2PL	0.026	0.305	0.077	94	71	141	82	328	121	14	761
1DispH	0.004	0.120	0.023	130	75	173	79	396	115	19	762
1DispL	0.004	0.081	0.017	140	72	177	78	363	108	49	711

Table 7.5. Continued.

	Risk [a]			Population size in 100 years		Population size in 50 years		Additional deer killed			
Model [b]	R_0 (100)	R_{25} (100)	R_{25} (50)	θ	SD	θ	SD	θ	SD	Min.	Max.
1KH	0.003	0.085	0.015	146	81	190	85	421	121	36	829
1KL	0.005	0.123	0.024	121	68	161	72	366	104	26	748
1RmH	0.000	0.007	0.002	241	77	246	76	532	84	143	808
1RmL	0.117	0.638	0.123	35	35	102	68	251	105	20	816
1SDH	0.004	0.100	0.018	134	73	175	77	395	110	41	760
1SDL	0.005	0.121	0.023	130	77	173	83	388	117	61	889
2Medium	0.003	0.133	0.025	122	71	164	75	409	117	42	891
2Cat1MH	0.003	0.099	0.018	135	74	175	77	432	118	59	889
2Cat1ML	0.007	0.181	0.033	109	69	156	78	390	120	38	832
2Cat1PH	0.003	0.104	0.017	133	73	176	78	432	120	50	912
2Cat1PL	0.007	0.160	0.031	112	68	155	74	389	116	33	831
2Cat2MH	0.001	0.064	0.006	132	67	172	71	425	108	85	840
2Cat2ML	0.015	0.223	0.059	112	75	158	81	394	128	29	822
2Cat2PH	0.001	0.051	0.007	144	69	183	71	449	109	64	814
2Cat2PL	0.031	0.348	0.090	86	66	133	79	343	125	18	787
2DispH	0.004	0.145	0.029	119	71	164	77	414	120	47	840
2DispL	0.005	0.099	0.018	128	69	168	75	376	111	41	790
2KH	0.004	0.121	0.020	131	76	175	81	435	127	54	876
2KL	0.005	0.146	0.026	113	65	154	70	383	109	52	745
2RmH	0.000	0.008	0.002	229	75	237	75	563	92	133	840
2RmL	0.136	0.703	0.147	31	32	94	64	262	108	16	790
2SDH	0.003	0.120	0.020	124	69	166	73	413	116	35	854
2SDL	0.005	0.152	0.029	120	74	163	80	406	123	29	842
3Medium	0.007	0.196	0.038	100	62	147	70	444	130	64	945
3Cat1MH	0.004	0.160	0.030	109	63	153	70	463	131	52	934
3Cat1ML	0.013	0.258	0.051	89	60	135	70	418	133	29	855
3Cat1PH	0.005	0.154	0.028	109	64	154	70	464	130	70	1002
3Cat1PL	0.010	0.234	0.043	89	58	136	66	420	126	27	854
3Cat2MH	0.002	0.110	0.012	108	59	152	66	458	120	80	947
3Cat2ML	0.026	0.303	0.081	90	64	136	74	421	141	27	899

Table 7.5. Continued.

	Risk [a]			Population size in 100 years		Population size in 50 years		Additional deer killed			
Model [b]	R_0 (100)	R_{25} (100)	R_{25} (50)	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Min.	Max.
3Cat2PH	0.004	0.108	0.015	114	62	158	69	476	125	46	917
3Cat2PL	0.046	0.441	0.116	67	56	118	72	372	136	22	821
3DispH	0.009	0.214	0.040	95	61	142	69	443	132	55	882
3DispL	0.007	0.133	0.026	109	60	150	68	400	120	29	870
3KH	0.006	0.182	0.029	105	65	153	73	467	137	62	1024
3KL	0.008	0.208	0.039	94	58	137	65	417	121	49	888
3RmH	0.000	0.014	0.004	209	72	220	71	629	105	161	955
3RmL	0.175	0.816	0.198	22	23	77	54	278	109	20	889
3SDH	0.006	0.174	0.033	100	59	146	67	445	125	46	880
3SDL	0.008	0.211	0.038	99	65	144	72	437	133	39	941
4Medium	0.015	0.277	0.052	77	52	125	62	468	137	47	999
4Cat1MH	0.008	0.228	0.041	85	54	132	63	491	139	41	1018
4Cat1ML	0.023	0.362	0.074	68	50	116	62	441	139	38	979
4Cat1PH	0.009	0.234	0.044	86	55	132	64	493	142	66	1018
4Cat1PL	0.017	0.334	0.062	69	49	116	60	443	134	65	966
4Cat2MH	0.005	0.184	0.021	84	50	130	59	485	129	85	966
4Cat2ML	0.040	0.388	0.107	70	54	118	66	448	150	37	992
4Cat2PH	0.003	0.140	0.016	94	53	140	58	512	128	68	1002
4Cat2PL	0.069	0.543	0.155	52	46	100	63	394	143	24	888
4DispH	0.017	0.314	0.058	73	51	122	62	470	141	39	985
4DispL	0.010	0.188	0.037	90	51	130	61	413	125	68	934
4KH	0.012	0.258	0.049	81	54	131	66	489	146	60	1045
4KL	0.054	0.547	0.120	40	32	83	45	470	139	68	1065
4RmH	0.000	0.020	0.005	189	68	200	67	689	119	179	1110
4RmL	0.254	0.902	0.265	15	17	63	45	296	110	18	872
4SDH	0.011	0.257	0.048	78	50	126	60	471	135	52	957
4SDL	0.016	0.312	0.061	75	54	123	65	462	144	17	1128

[a] R_0 *(100)* – risk of extinction in 100 years.

R_{25} *(100)* – risk of population falling below 25 individuals in 100 years.

R_{25} *(50)* – risk of population falling below 25 individuals in 50 years.

[b] For model descriptions, see Table 7.1.

Table 7.6. Comparison of risk estimates [a] (medium, min., max.) by extinction threshold and management scenario.

Threshold	R_0			$R(100)$			$R(50)$		
Scenario [b]	Min.	Medium	Max.	Min.	Medium	Max.	Min.	Medium	Max.
25 Individuals									
S0	0.000	0.001	0.026	0.001	0.020	0.119	0.000	0.005	0.029
S1	0.000	0.004	0.117	0.007	0.103	0.638	0.002	0.018	0.123
S2	0.000	0.003	0.136	0.008	0.133	0.703	0.002	0.025	0.147
S3	0.000	0.007	0.175	0.014	0.196	0.816	0.004	0.038	0.198
S4	0.000	0.015	0.254	0.020	0.277	0.902	0.005	0.052	0.265
50 Individuals									
S0	0.000	0.001	0.027	0.010	0.070	0.328	0.005	0.023	0.095
S1	0.000	0.004	0.112	0.049	0.286	0.842	0.018	0.086	0.298
S2	0.000	0.005	0.136	0.053	0.322	0.873	0.020	0.096	0.337
S3	0.000	0.007	0.177	0.074	0.406	0.936	0.026	0.119	0.413
S4	0.000	0.013	0.244	0.106	0.535	0.978	0.039	0.172	0.521
100 Individuals									
S0	0.000	0.001	0.026	0.115	0.281	0.586	0.055	0.121	0.290
S1	0.000	0.004	0.116	0.317	0.658	0.975	0.141	0.324	0.640
S2	0.000	0.004	0.125	0.345	0.712	0.982	0.157	0.354	0.675
S3	0.000	0.008	0.176	0.422	0.796	0.996	0.203	0.423	0.783
S4	0.000	0.014	0.248	0.504	0.892	0.999	0.251	0.514	0.875

[a] R_0 – risk of extinction in 100 years.

$R(100)$ – risk of population falling below given threshold in 100 years.

$R(50)$ – risk of population falling below given threshold in 50 years.

[b] Management scenarios: S0 (Scenario 0) = no change, S1 (Scenario 1)= road improvement, S2 (Scenario 2) = road improvement + 100 houses, S3 (Scenario 3) = road improvement + 300 houses, and S4 (Scenario 4) = road improvement + 500 houses.

Table 7.7. Sensitivity (difference in risk estimates between high and low parameter values) of model results to parameters for Scenario 0 (current status).

Threshold		Risk [a]			Difference in High-Low		
Parameter [b]	Adjustment	R_0 *(100)*	*R (100)*	*R (50)*	R_0 *(100)*	*R (100)*	*R (50)*
25 Individuals							
Cat. 1 Multiplier	High	0.000	0.014	0.003	0.001	0.018	0.004
	Low	0.002	0.032	0.008			
Cat. 1 (*P*)	High	0.000	0.011	0.003	0.000	0.012	0.002
	Low	0.001	0.023	0.006			
Cat. 2 Multiplier	High	0.000	0.003	0.001	0.004	0.062	0.020
	Low	0.004	0.065	0.020			
Cat. 2 (*P*)	High	0.000	0.003	0.001	0.008	0.100	0.028
	Low	0.008	0.103	0.029			
Dispersal	High	0.001	0.020	0.004	0.001	0.004	0.001
	Low	0.001	0.016	0.003			
K	High	0.000	0.017	0.005	0.001	0.004	0.000
	Low	0.001	0.020	0.005			
Rmax	High	0.000	0.001	0.000	0.026	0.118	0.003
	Low	0.026	0.119	0.003			
Fecundity SD	High	0.000	0.014	0.003	0.001	0.006	0.003
	Low	0.001	0.020	0.006			
50 Individuals							
Cat. 1 Multiplier	High	0.000	0.055	0.019	0.001	0.045	0.012
	Low	0.001	0.100	0.031			
Cat. 1 (*P*)	High	0.000	0.055	0.019	0.001	0.035	0.009
	Low	0.001	0.090	0.029			
Cat. 2 Multiplier	High	0.000	0.018	0.005	0.005	0.156	0.065
	Low	0.005	0.174	0.069			
Cat. 2 (*P*)	High	0.000	0.020	0.006	0.009	0.227	0.089
	Low	0.009	0.247	0.095			
Dispersal	High	0.001	0.072	0.023	0.000	0.001	0.002
	Low	0.001	0.071	0.024			

Table 7.7. Continued

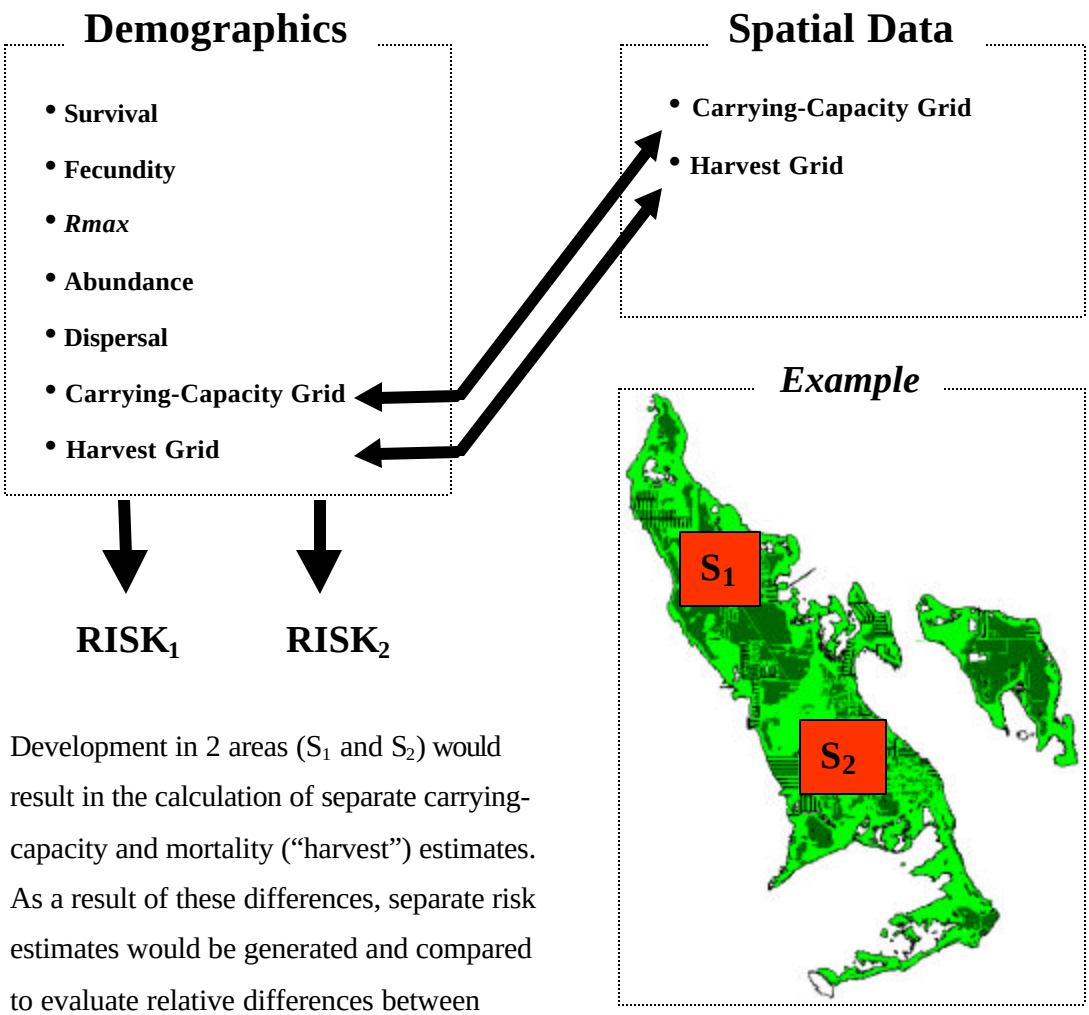
Threshold		Risk [a]			Difference in High-Low		
Parameter [b]	Adjustment	R_0 *(100)*	*R (100)*	*R (50)*	R_0 *(100)*	*R (100)*	*R (50)*
K	High	0.000	0.059	0.018	0.000	0.027	0.010
	Low	0.001	0.086	0.028			
Rmax	High	0.000	0.010	0.005	0.027	0.318	0.083
	Low	0.027	0.328	0.088			
Fecundity SD	High	0.000	0.067	0.023	0.001	0.011	0.005
	Low	0.001	0.078	0.028			
100 Individuals							
Cat. 1 Multiplier	High	0.000	0.233	0.102	0.001	0.125	0.061
	Low	0.001	0.358	0.163			
Cat. 1 (*P*)	High	0.001	0.235	0.101	0.000	0.088	0.051
	Low	0.001	0.323	0.152			
Cat. 2 Multiplier	High	0.000	0.155	0.060	0.005	0.304	0.176
	Low	0.005	0.459	0.236			
Cat. 2 (*P*)	High	0.000	0.135	0.057	0.008	0.424	0.232
	Low	0.008	0.559	0.290			
Dispersal	High	0.000	0.274	0.121	0.000	0.019	0.006
	Low	0.000	0.294	0.127			
K	High	0.000	0.238	0.100	0.001	0.094	0.042
	Low	0.001	0.332	0.142			
Rmax	High	0.000	0.115	0.055	0.026	0.471	0.215
	Low	0.026	0.586	0.270			
Fecundity SD	High	0.000	0.257	0.114	0.000	0.055	0.027
	Low	0.001	0.312	0.141			

[a] R_0 – risk of extinction in 100 years.

R (100) – risk of population falling below given threshold in 100 years.

R (50) – risk of population falling below given threshold in 50 years.

[b] For parameter descriptions, see Table 7.2.



Development in 2 areas (S_1 and S_2) would result in the calculation of separate carrying-capacity and mortality ("harvest") estimates. As a result of these differences, separate risk estimates would be generated and compared to evaluate relative differences between development scenarios

Fig. 7.1. Conceptual Key deer population model.

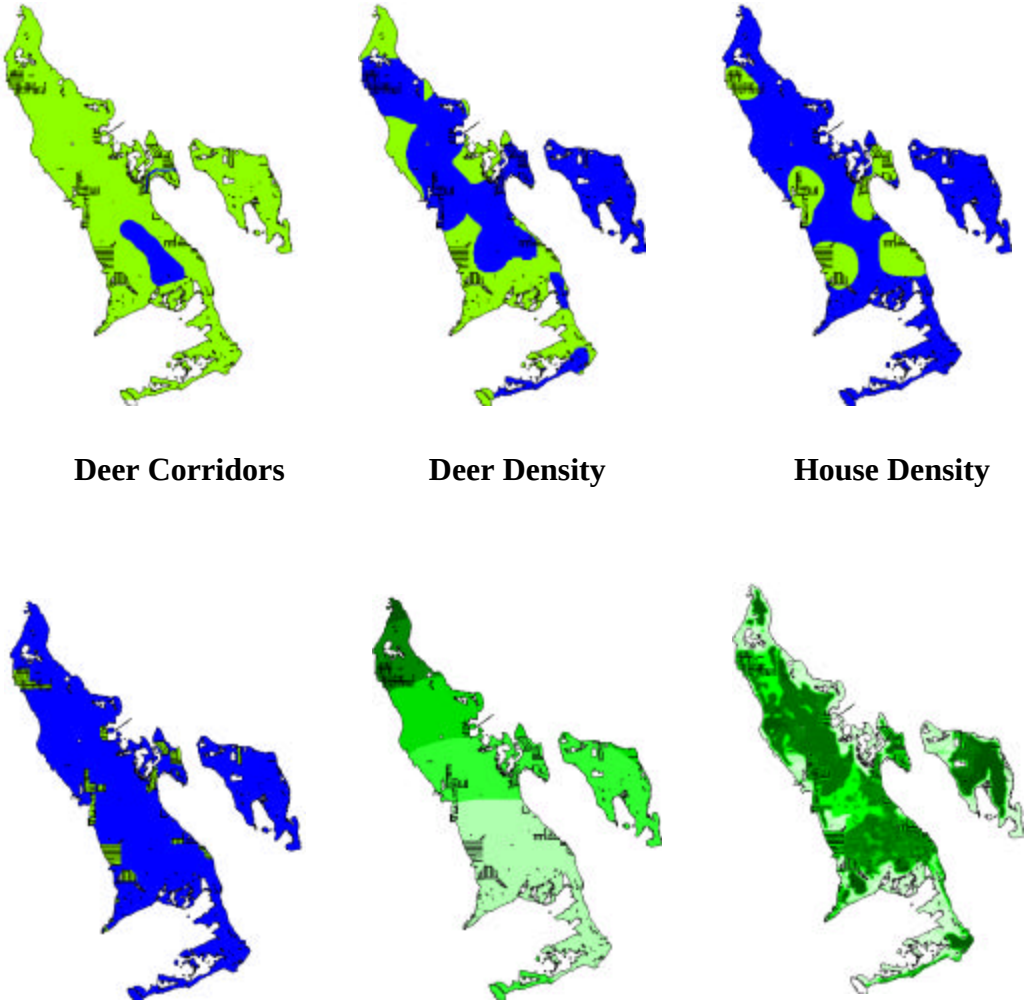


Fig. 7.2. Six grid layers used to generate weighting factor grid (darker shades = higher deer value).

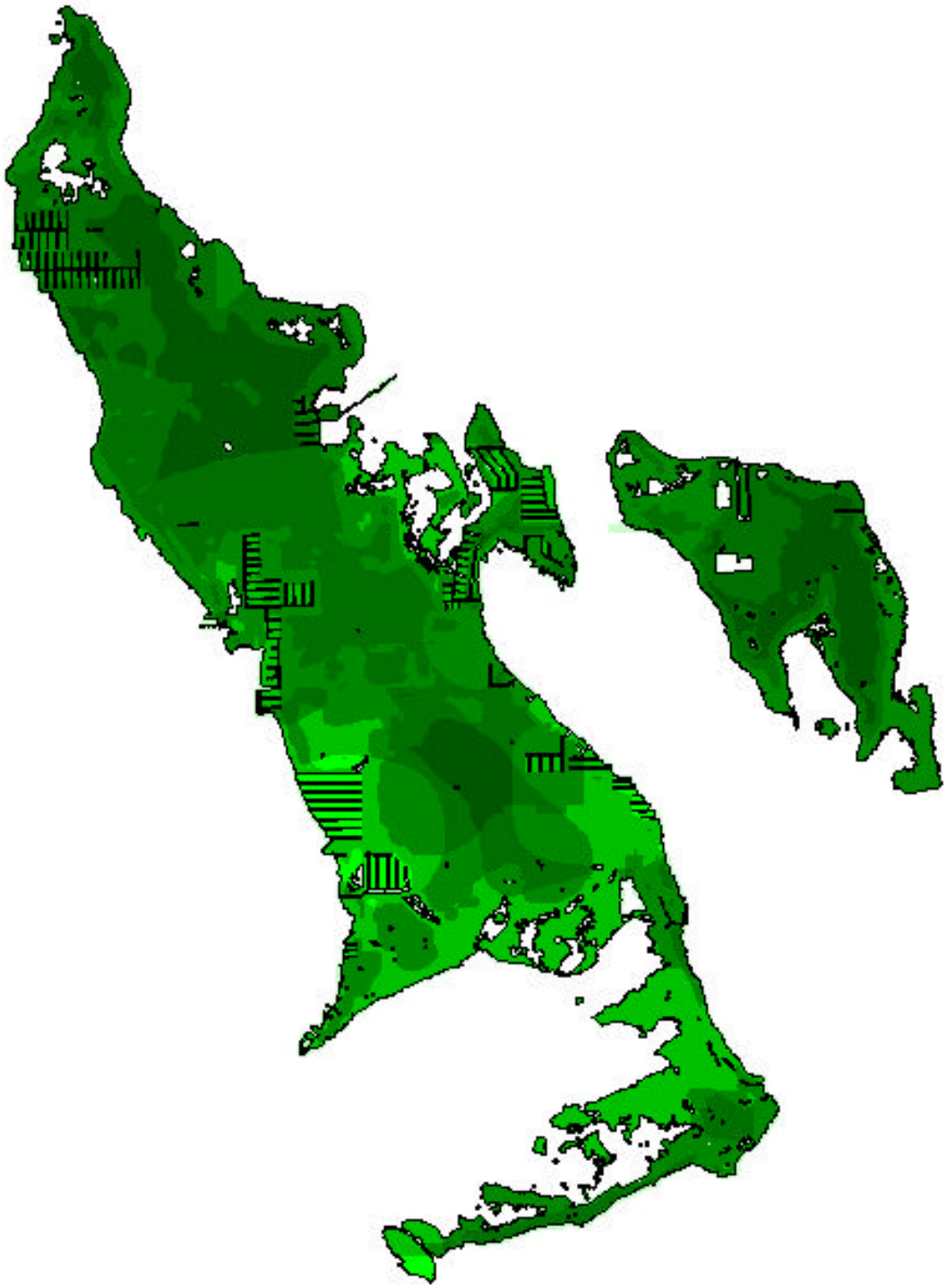
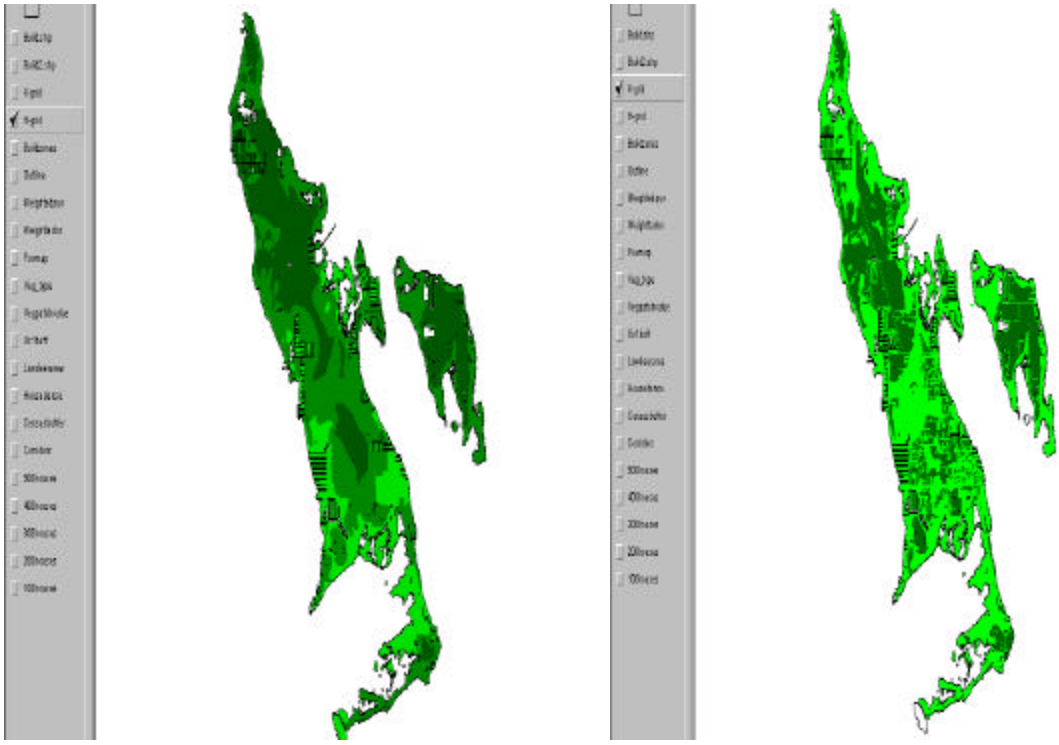


Fig. 7.3. Weighting factor grid (darker shades = higher deer value) used to estimate deer impact under different development scenarios.



Harvest Grid **Carrying-Capacity Grid**

Fig. 7.4. Harvest (left) and carrying-capacity (right) grids used to estimate percent mortality increase and changes in carrying-capacity, respectively, under different development scenarios (darker shades = greater deer impact).

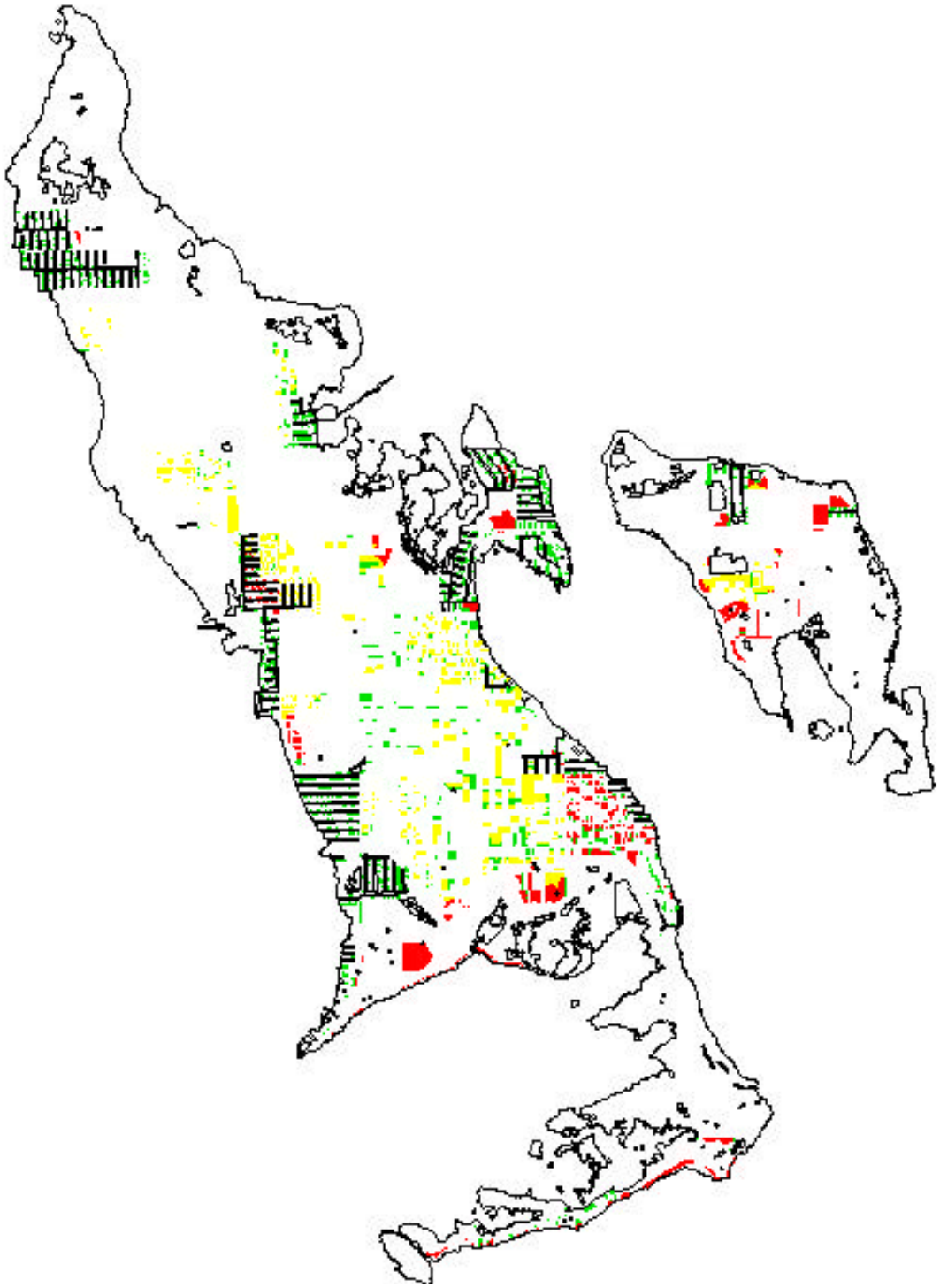


Fig. 7.5. Distribution of privately owned, upland, vacant lots (PUV) by habitat type (red = hammock, green = urban, yellow = pineland) on Big Pine and No Name keys.

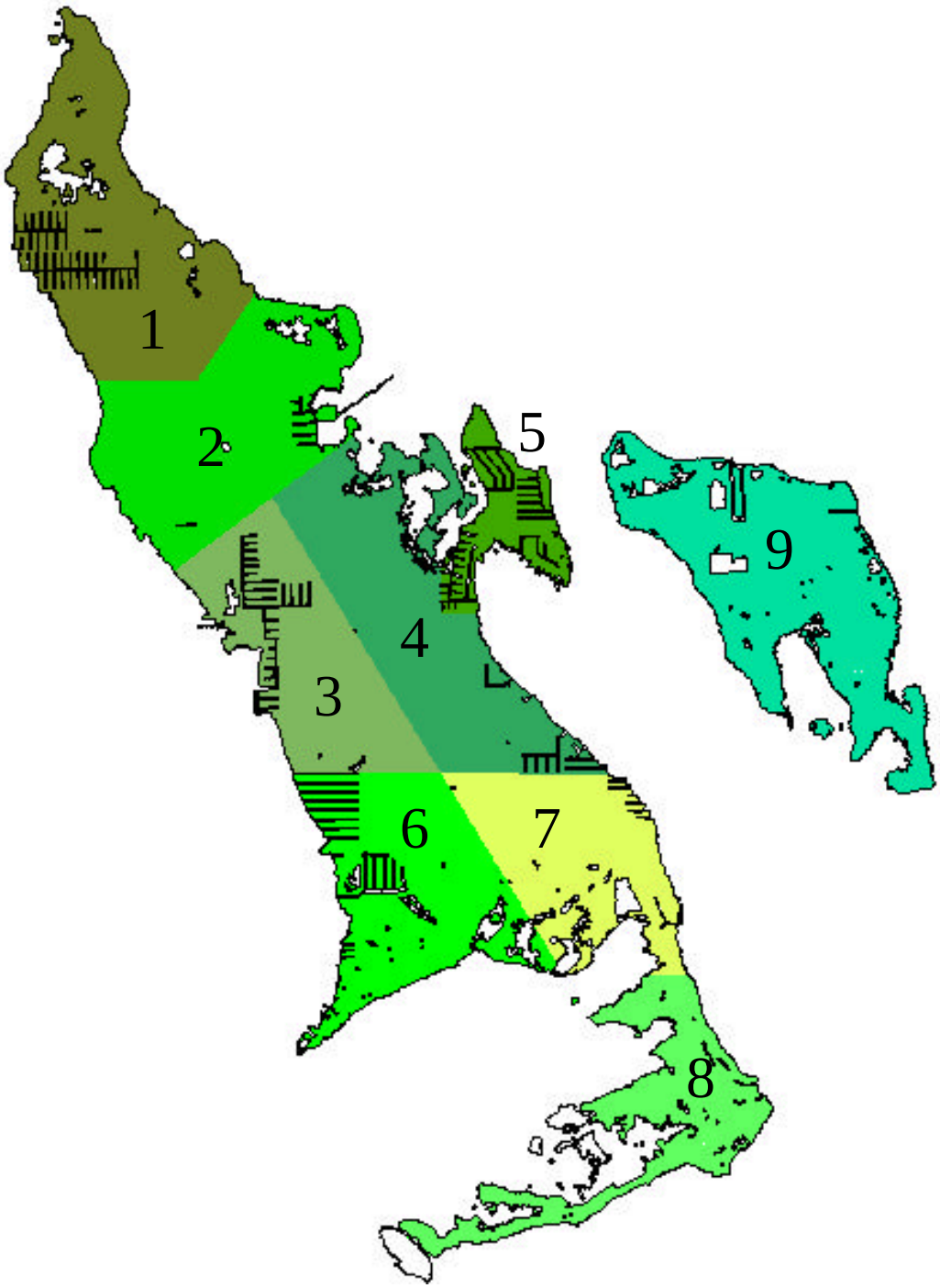


Fig. 7.6. Building zones on Big Pine and No Name keys.

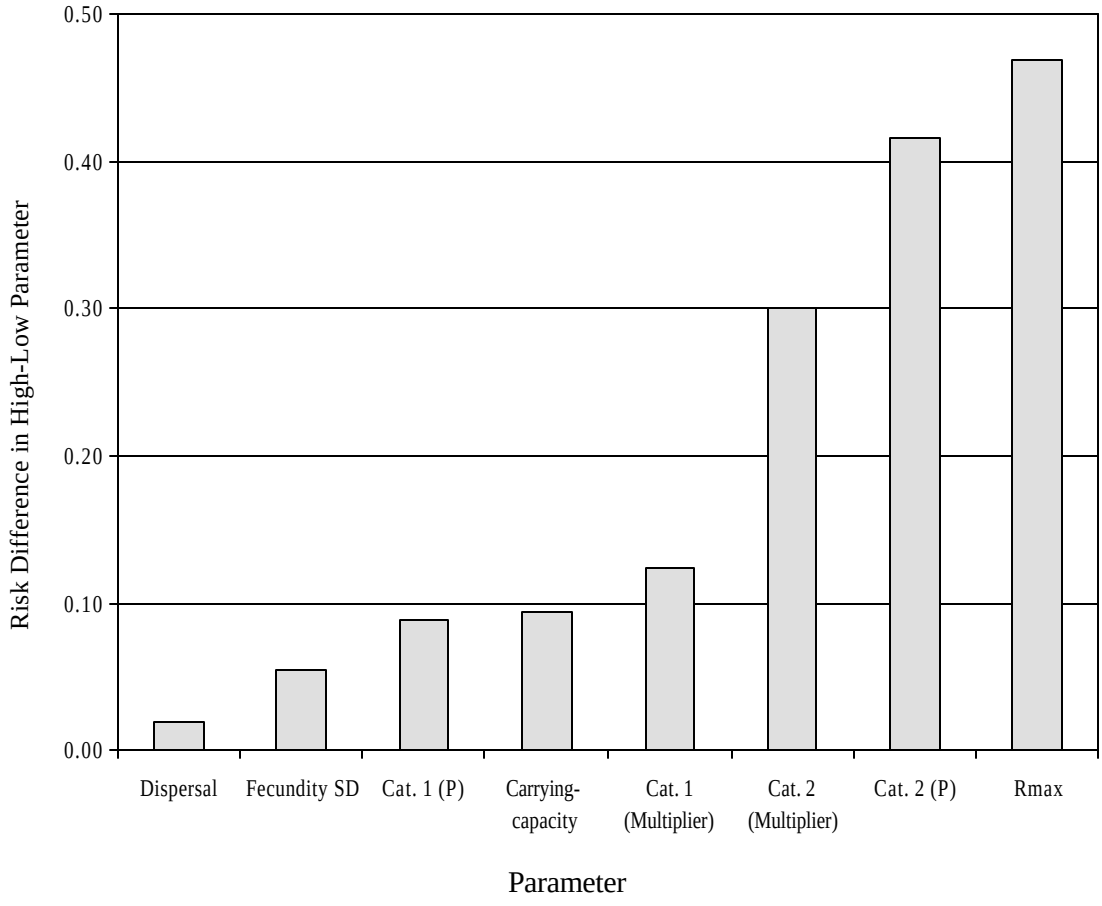


Fig. 7.7. Sensitivity (difference in risk estimates between high and low parameter values) of model results to parameters for all scenarios and extinction thresholds.

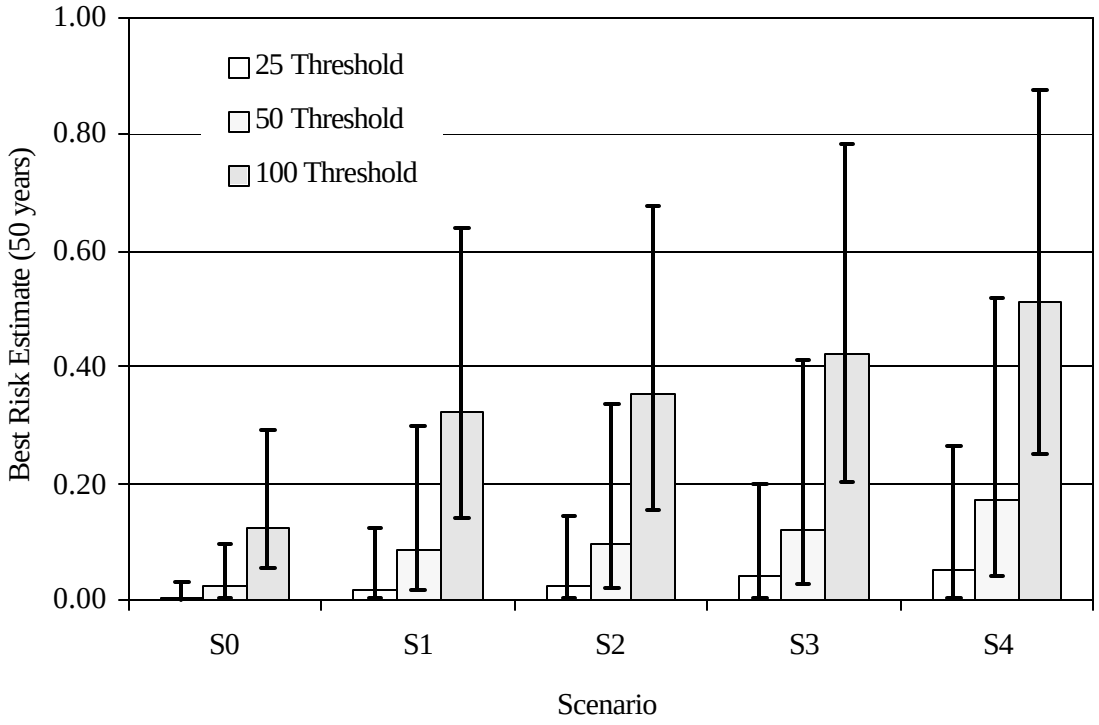


Fig. 7.8. Risk (shaded area = best estimate, error bar = low and high values) by management scenario of falling below threshold at least once in 50 years.

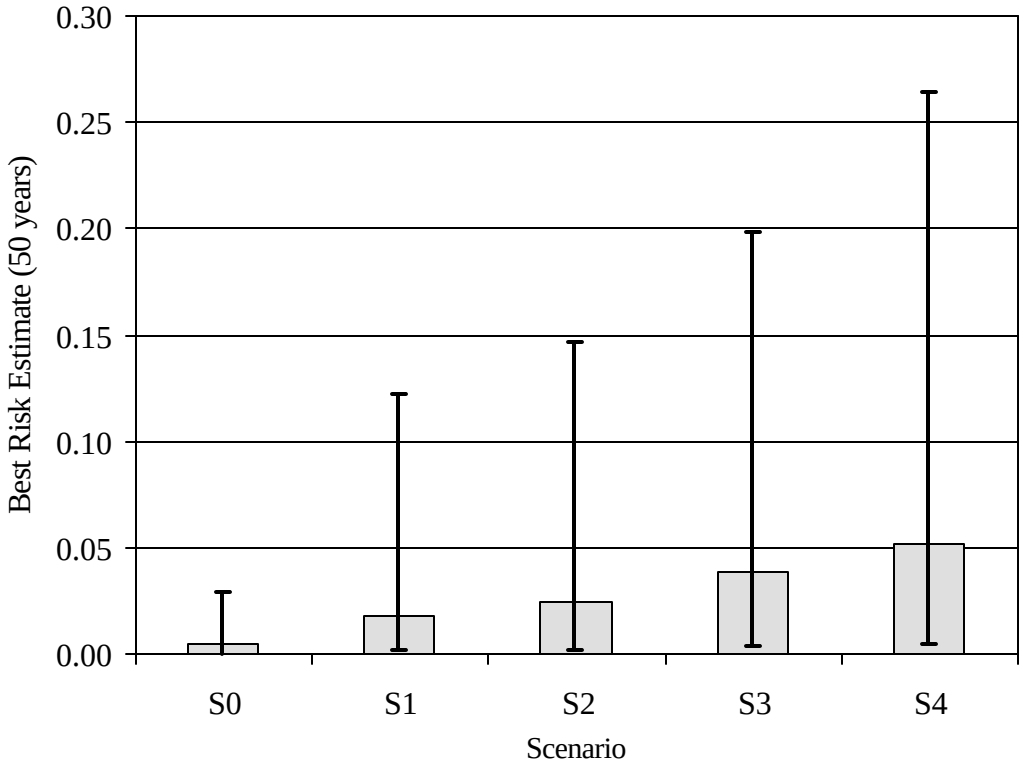


Fig. 7.9. Risk (shaded area = best estimate, error bar = low and high values) by management scenario of falling below 25 individuals at least once in 50 years.

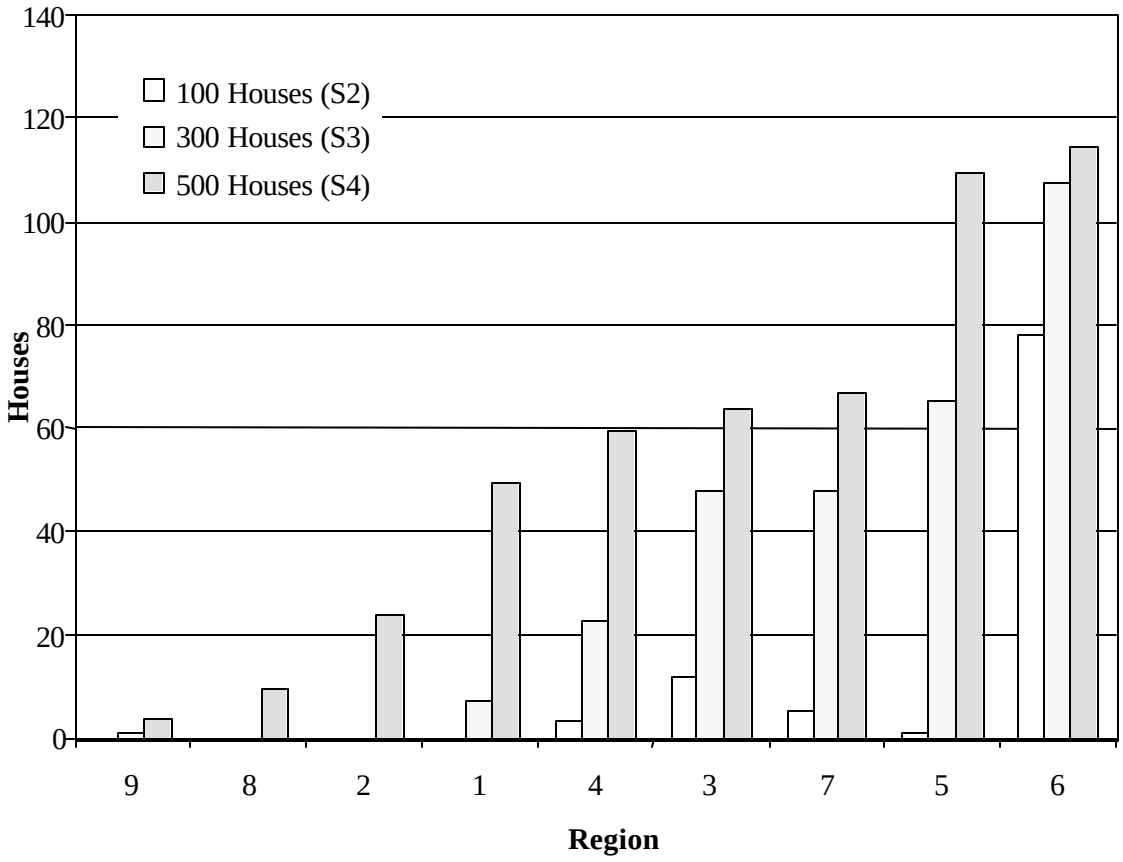


Fig. 7.10. Distribution of development by scenario (number of houses) and region.

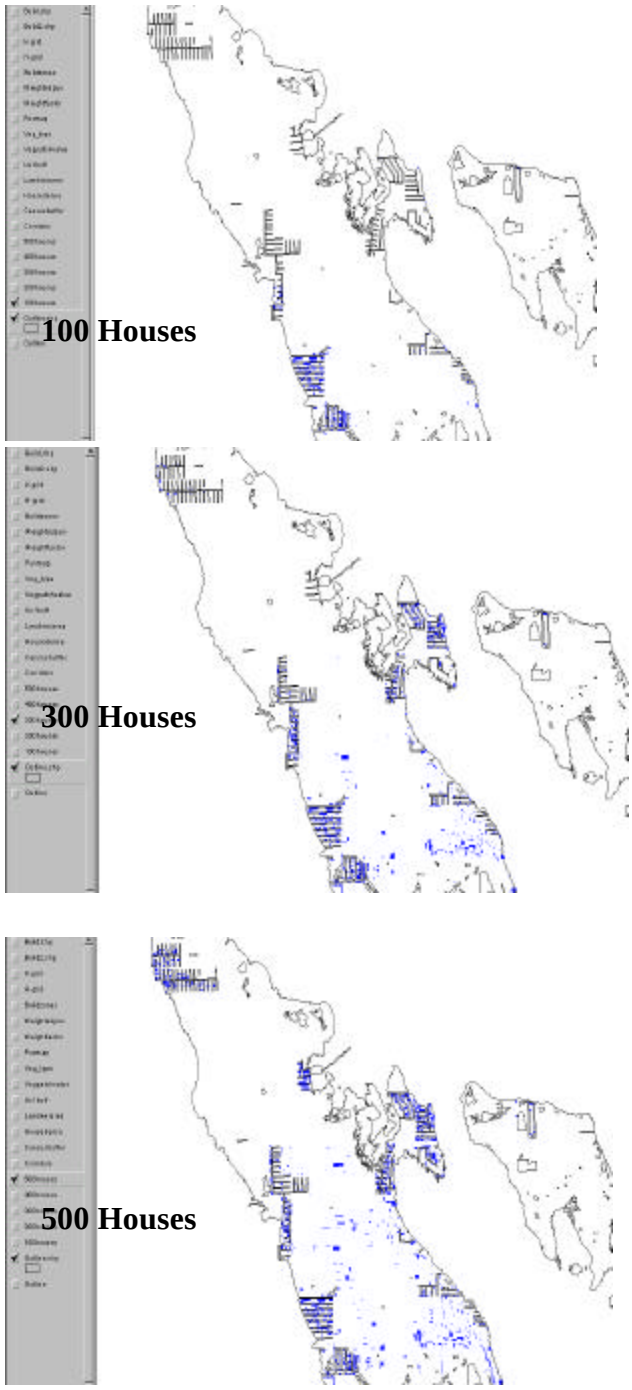


Fig. 7.11. Distribution of development (blue areas) on Big Pine and No Name keys under 3 different management scenarios.

DISCUSSION

A demographic and spatially-structured model was developed in a PVA for the endangered Florida Key deer. The model provides a framework for evaluating impacts on Key deer in an HCP for Big Pine and No Name keys. In the last several years, conflicts between land owners, residents, and environmental groups has escalated due to land use issues, the building moratorium, and traffic congestion on these islands. It is proposed the HCP will identify areas important to the conservation of Key deer and offer island residents some relief from building restrictions.

Deer Viability

Model results suggest the deer population has a relatively low risk of decline (Fig. 7.9) and that a certain degree of development might occur on the islands depending on the acceptable level of risk for HCP decision-makers. One advantage of the Key deer model and the proposed planning approach is the holistic evaluation of development in the core of the Key deer range rather than evaluation by individual-projects. The model can provide decision-makers with results that incorporate uncertainty and variability in risk projections for this endangered deer population. Output, illustrated in the chapter, includes changes in risk to the Key deer metapopulation in a variety of forms. Furthermore, model users can understand the effect of uncertain input and make decisions with full knowledge of these uncertainties (Akcakaya and Sjogren-Gulve 2000).

Users of the model are urged to consider relative risks rather than absolute risks in making management decisions (Akcakaya and Sjogren-Gulve 2000). For example, how does the viability of the species change between Scenario 1 versus Scenario 2? Furthermore, users should focus on the risk of decline below a critical population level (quasi-extinction threshold) rather than the risk of extinction because of the uncertainties in modeling small populations (Akcakaya and Sjogren-Gulve 2000). Lastly, short time horizons (e.g., 50 years) should be considered in making conservation decisions rather than long time horizons (e.g., 100 years), particularly where human impacts are being evaluated, as is the case in the Key deer model. Model predictions for long time horizons require making more assumptions that might not be realistic. For a review of use and interpretation of PVA results, see Akcakaya and Sjogren-Gulve (2000).

Model Refinement

The sensitivity analysis gives information about which parameters need to be estimated more carefully in the refinement of the Key deer model. For example, the maximal growth rate (R_{max}) resulted in the greatest uncertainty in the model sensitivity analyses. Data collection in the future should attempt to improve estimates of the R_{max} to reduce the amount of model uncertainty. For example, the collection of survey data during 2 short periods such as conducting 5-7 surveys in the first week of April and first week of October would provide a better estimate of R_{max} (Chapter V). Specifically, intense spring and fall counts would estimate (1) population changes among years and (2) population recruitment between years. Furthermore, fawn survival in the model was adjusted to avoid what was an overestimate (Chapter II). It is recommended that Key deer reproductive parameters can be improved by (1) radio collaring fawns < 4 months which to improve fawn survival estimates used in model and (2) evaluation of reproductive status from necropsied Key deer (Chapter II). With the current Key deer model, improvements as described above can be used to further refine model parameters, thus refining model outputs or results (Akcakaya 2000, Akcakaya and Sjogren-Gulve 2000).

Model results also were sensitive to the annual probabilities and hypothesized impacts of severe hurricanes (Category 4-5, Fig. 7.7). The sensitivity of model results to severe hurricanes (Category 4-5) is not surprising. Previous researchers have hypothesized that hurricanes might cause the Key deer population to go extinct (Folk 1991), however, little is known regarding the impacts of severe hurricanes on the deer herd (Chapter VI). Due to the limited knowledge on the expected hurricane impacts (changes in abundances) and probabilities of storm occurrences, a wide range of parameter estimates was used (Table 7.2). The long-term growth rate (eigenvalue) was above 1.0 in the stage matrix, which suggests declines and extinctions occurred mostly due to catastrophes (Akcakaya 1998). Because insurance against such threats to the deer population cannot be avoided, a captive propagation program to ensure the survival of the population is strongly recommended.

Conservation Planning

Problems in conservation planning and wildlife management are increasing with changes in and demands on land shared with threatened or endangered species (McCullough 1996, Akcakaya and Sjogren-Gulve 2000). Use of PVA's provides conservationists and managers with a tool to determine future development in light of risk to threatened and endangered populations. Such was the case in the study of Florida Key deer. A demographic and spatially-

structured population model was developed to aid decision makers in conservation planning in the Florida Keys. In addition, users of the model were provided with an array of risk estimates and other assessment end points, as well as a framework to plan the future of these 2 islands and this endangered deer herd. Distribution of development by number of houses, for example, can be used to generate a zoning map that can be used to guide development in the future. Furthermore, model results can assist federal, state, and county agencies in future land acquisition programs.

A common criticism of PVA's is that they do not explicitly incorporate economic factors in conservation planning (Boyce 1992). However, due to the quantitative nature of PVA results, ecological benefits (reduction of population risk) can be compared to economic costs (dollars). For example, the reduction of risk (defined in this example as a population falling below threshold in 50 years) can be compared to the total assessed land value from tax roll (defined as the amount of capital needed to buy the remaining privately-owned vacant lots on Big Pine and No Name Keys). Comparisons of this sort also allow decision-makers to determine the amount of capital necessary to implement a conservation program.

Finally, the Key deer model serves as an important management tool for the endangered Key deer and other populations of white-tailed deer as well. For example, the impact of translocations to overall metapopulation viability can be evaluated *a priori*. In addition, the model can be used to evaluate options for population control in the management of white-tailed deer populations (McShea et al. 1997).

CHAPTER VIII

CONCLUSIONS AND IMPLICATIONS

The purpose of this chapter is to provide a summary of the dissertation. This chapter will begin by summarizing research highlights from previous chapters in the dissertation. Management implications from research findings will then be presented, reviewed, and critiqued in light of recovery criteria from the Key Deer Recovery Plan (USFWS 1999).

RESEARCH HIGHLIGHTS

Urban Development

Increases in urban development, habitat fragmentation, and human-deer interactions historically have been viewed as threatening the Key deer population (Klimstra et al. 1974, Folk 1991). Study results support some of these concerns but also dispel some of the myths regarding the impacts of urban development on Key deer. Urban development is a double-edged sword as it has been both beneficial and detrimental to the deer population. Historically, the majority of urban development occurred in marginal habitats such as mangrove and buttonwood forests (Chapter III). The development of these habitat types resulted in the creation of "uplands" which provided food and freshwater resources to Key deer that were not previously available in these areas (Chapter III, Gallagher 1991). Population increases in white-tailed deer herds due to urbanization has been well documented throughout the southeastern United States (McShea et al. 1997). Thus, it is reasonable to assume that urban development is partly responsible for the increase in the deer herd in the last 30 years (Chapters III and V, Fig. 3.11).

Urban development also has had negative impacts on the Key deer. For example, highway mortality continues to account for the majority (50%) of the total Key deer mortality (Chapter II). Other human-related mortality factors, such as fence entanglement and dog-kills, have increased in the last 30 years (Chapter II). The relationship between urban development and Key deer numbers can be described as bell-shaped (Fig. 3.11), with too much development having a negative impact on the population at some level. Unlike development in the past which primarily occurred in marginal habitats (e.g., mangrove and buttonwood), future development would be expected to occur in upland habitats (e.g., pinelands and hammocks) and would not be expected to have the same positive benefits previously observed (Chapter III).

Deer Numbers

Since Key deer were listed in 1967, management of the deer herd focused on increasing deer numbers (USFWS 1999). Herd health indices, however, suggest that population increases over the last 30 years have placed the deer population at or near carrying capacity on Big Pine and No Name keys (Nettles et al. 2001, Chapter IV). Maintaining high deer densities is not recommend because of potential damage to habitat and the increased likelihood of disease transmission (McShea et al. 1997, Nettles et al. 2001). A new management paradigm for the Key deer is necessary. For example, in this new paradigm herd health and habitat quality would be important factors rather than just deer numbers. In order to adopt this management philosophy, changes in management perspectives or how stakeholders perceive the management of the deer herd are necessary. For example, the understanding and acceptance by stakeholders that a *reduction* in deer numbers when deer densities are high would benefit the Key deer herd is radically different from the old management perspective. The first step in this process would include modifying the Recovery Plan to allow refuge managers to implement management practices (e.g., use of contraception) that are currently not available in the management of Key deer.

Stochastic Events

Stochastic events such as hurricanes or diseases will continue to threaten the viability of the deer herd (Chapter VI, Nettles et al. 2001). The only safeguard against the risk of population extinction is increasing the number of deer on other islands via translocations, and/or initiating a captive propagation program on the mainland (Chapter VI). Acceptance of translocations and captive propagation as useful management strategies also will require stakeholders to understand the benefits of such strategies in the Key deer's recovery. Public education will play a vital role in increasing stakeholder awareness and acceptance of such strategies.

Habitat Conservation Planning

Many of the management strategies discussed above can be addressed through the successful implementation of a Habitat Conservation Plan. Model simulations suggest a certain degree of development can occur on Big Pine and No Name keys without jeopardizing the overall viability of the deer population (Chapter VII). Model results can be used to direct future development in areas where the least impact to the deer population would be expected. Validation of model predictions is recommended by the continuation of monitoring and research efforts.

MANAGEMENT IMPLICATIONS

A review and critique of the Key Deer Recovery Plan was conducted to identify and summarize important recovery criteria supported by research findings in this dissertation. The continued recovery of the Key deer population can be summarized in 6 steps: (1) land acquisition, (2) habitat management, (3) population management, (4) public outreach, (5) monitoring and research, and (6) habitat conservation planning. Recommended recovery criteria are prioritized by each section and discussed below:

Land Acquisition

1. Acquire unprotected Key deer habitat (H 1.1, USFWS 1999). Support federal, state, and county acquisition efforts, particularly for habitats currently most threatened by development (i.e., hammocks, pineland, Chapter III).
2. Determine the amount and the configuration of habitat necessary to support a viable deer population with a PVA (H 3.2.3, USFWS 1999). Identify areas that are not important to the viability of the deer herd and allow these areas to be developed.

Habitat Management

1. Eliminate threats from invasive exotic flora (e.g., Brazilian pepper, Australian pine) and fauna (H 1.2, USFWS 1999). Continue restoration efforts by federal, state, and county agencies to improve Key deer habitat by the removal and treatment of invasive exotics. Maintain treated sites with follow-up visits.
2. Continue the use of prescribed fire to improve habitat quality of pinelands (H 1.2.5, USFWS 1999). Selection of burn sites should be based on area (> 4 ha tracts), time since the last burn, and existing firebreaks to maximize efforts by fire personnel. Ideally, large, contiguous tracts of pinelands should be burned on a 7-10 year cycle (Carlson et al. 1993).
3. Improve freshwater resources throughout the range of the deer (H 2.3, Folk 1991, USFWS 1999). The removal of silt and debris to increase the holding capacity of waterhole basins is recommended.
4. Minimize the amount of fencing within the Key deer range. Fence entanglement by Key deer accounts for nearly 8% of total deer mortality in addition to fragmenting Key deer habitat (Chapters I-II). The Key Deer Recovery Plan does not adequately address fencing on Big Pine and No Name keys. As a result, fencing guidelines for existing and future

development is strongly recommended. Lands to be purchased also should require the removal of old fences prior to acquisition.

5. Reduce highway mortality by improving visibility on roads (e.g., widening road shoulders, lighting, S 2.5, USFWS 1999).

Population Management

1. Establish reclassification criteria that can be realistically achieved (S 6, USFWS 1999). Currently, some recovery criteria are unobtainable. For example, the Key Deer Recovery Plan states the Key deer will be down-listed "when stable populations of the Key deer are distributed throughout its historic range; and two, additional, stable populations have been established along the periphery of the historic range" (recovery criteria, USFWS 1999). For the latter, this requires the establishment of Key deer populations in Key West and Marathon, both of which are nearly completely built-out and would not support deer populations. Such criteria are unreasonable and do not allow for a step-down process necessary in a Recovery Plan.
2. Reduce deer densities, if necessary, to maintain a healthy deer population. The most challenging aspect in the future management of the Key deer is realizing the limitations of the habitat to support an increasing deer population. As previously mentioned, maintaining high densities of Key deer is not desirable because of potential habitat degradation and increased risk in disease transmission (McShea et al. 1997, Davidson and Doster 1997, Nettles et al. 2001). Future Key deer management will require changes in recovery criteria, which emphasize other parameters such as habitat quantity/quality and herd health.
3. Conduct Key deer translocations, if necessary, to bolster declining local populations (S 2.1, USFWS 1999). Deer translocations are recommended to reduce risks to the population such as disease outbreaks or hurricanes. Prior to conducting deer translocations, however, biologists should determine factors that might limit the self-increase of deer numbers on other islands (Nielsen 1988), and determine the compatibility of expected herbivory to other management objectives (e.g., plant diversity).
4. Reduce highway mortality (S 2.5.3, USFWS 1999). Highway mortality currently benefits the deer population by reducing the overall population size, and serving as an alternative form of predation or hunting (Chapter II). Despite the biological benefits in herd reduction, reducing highway mortality is recommended because of human safety concerns and because it is an inhumane method of reducing deer numbers. Alternative forms of herd reduction,

such as contraception, should be developed to allow greater flexibility in managing the deer herd in the future.

5. Initiate a captive propagation program (S 2.8, USFWS 1999). Currently, the Key Deer Recovery Team believes captive propagation is unnecessary (USFWS 1999). Key deer susceptibility to severe storms, however, warrants the implementation of a captive breeding program for several reasons. First, to ensure the survival of the Key deer population an alternative "refuge" protected from natural disturbances such as hurricanes is needed (Chapter VI). In case of a catastrophic hurricane (e.g., Category 5, storm surge > 10 m), deer stock can then be used restock the deer range. Second, it is believed the establishment of a captive propagation program would diminish the importance of other recovery actions such as land acquisition (Seal and Lacy 1990). Key deer recovery requires the support of land acquisition programs *and* other recovery strategies such as captive propagation; successful recovery of the Key deer requires the use of multiple strategies rather than a single approach.

Public Outreach

1. Prepare informational material for the public about Key deer and management strategies (S 5, USFWS 1999). Public outreach should include traditional information (i.e., why biologists use prescribed fire, invasive exotic plant removal, problems with feeding) in addition to information that would aid the transition and implementation of the new management paradigm previously discussed.
2. Remove Recovery Plan criteria that are not directly related to the recovery of the Key deer (e.g., S 2.6.1.1-4, H 1.2.5.1. and H 1.2.6., USFWS 1999). For example, "prohibiting campfires in the National Key Deer Refuge" (H 1.2.5.1, USFWS 1999) is not directly related to Key deer recovery and serves no purpose in the Recovery Plan.

Monitoring and Research

1. Continue Key deer necropsies (S 3.3.7, USFWS 1999, Chapters II and VII). Deer necropsies should focus on collecting herd productivity data which are lacking from previous studies.
2. Continue monthly surveys of Key deer populations on Big Pine and No Name keys (S 4, USFWS 1999, Chapter IV). Survey data can continue to serve as an index to population size and be used to make management recommendations for the deer herd.
3. Collect demographic data using radio telemetry on Key deer fawns (S 4, USFWS 1999). Demographic data on Key deer fawns (< 6 months of age) is lacking from previous studies

(Silvy 1975, Chapters II and VII). Current reproductive estimates are particularly important for refining the PVA model (Chapter VII).

4. Collect demographic data using radio telemetry on various deer populations other than deer on Big Pine and No Name keys (S 3.3.4, S 4, USFWS 1999). Demographic data on other Key deer populations are lacking from previous studies (Silvy 1975, current study).

Habitat Conservation Planning

1. Implement an HCP for Key deer (Chapter VII). Many land use issues can be resolved with the successful implementation of an HCP.
2. Use a PVA to evaluate different development scenarios (Chapter VII). Using model results, HCP applicants (FDOT, Monroe County, DCA) with the technical guidance of USFWS and FFWCC biologists can outline the direction of future development and modify the comprehensive plan accordingly (Monroe County Growth Management Division 1992).
3. Monitor and validate PVA model predictions. Refine the model, if necessary (Chapter VII).

In the future, the continued recovery and management of the Key deer and its habitat will offer many challenges for managers, biologists, and community leaders. An attempt to balance the needs of the Key deer and offer regulatory relief to residents of these 2 islands can be accomplished with the successful implementation of the HCP. In this planning process, decisions can be made based on the current biology of the Key deer in addition to incorporating other social values. Future management of the Key deer can be summarized with some advice offered by Silvy (1975) nearly 3 decades ago:

> *Simply an increase in numbers (such as 50 to 350) of an endangered population cannot be interpreted as being saved from extinction. The fate of any animal, especially the Key deer, is directly related to those factors, which effect changes in the habitat of which it is a product. In the Florida Keys, it is the habitat that is currently endangered, but as the habitat changes, so will the deer and other native wildlife. The long-term effects of these changes must be considered, and management to ensure the future existence of the deer must be planned to provide adequate and acceptable habitat in the future.*

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