DISTRIBUTION AND ABUNDANCE OF ENDANGERED FLORIDA KEY

DEER ON OUTER ISLANDS

A Thesis

by

DOMINIQUE ELIJAH WATTS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2006

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,   Roel R. Lopez
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ABSTRACT

Distribution and Abundance of Endangered Florida Key Deer on Outer Islands.

(December 2006)

Dominique Elijah Watts, B. S., New Mexico State University

Chair of Advisory Committee: Dr. Roel R. Lopez

Status assessments are compulsory to efficacious management of large-mammal populations, particularly for endangered species such as the Florida Key deer (*Odocoileus virginianus clavium*). However, a dearth of data regarding these basic demographic parameters has limited status assessment and management of Key deer on outer islands. Traditional survey techniques for Key deer on Big Pine and No Name keys include road-counts, strip-counts, and mark-recapture methods. However, practical limitations render traditional survey techniques impractical for application on outer islands. Thus, assessment of current status and appropriate management is limited by a paucity of information regarding Key deer on outer islands. The purpose of my study was to evaluate the utility of infrared-triggered cameras and forward-looking infrared thermography (FLIR) to monitor occupancy and abundance of Key deer on outer islands, and to obtain baseline information regarding current distribution and abundance of Key deer in these areas. In addition, I wanted to further evaluate the advantages and disadvantages inherent in using baited camera-stations to estimate abundance of large mammal populations. I compared 3 frequently applied methods to estimate abundance from camera-based survey data. All outer islands exhibited estimated abundances considerably below carrying capacities, with larger populations occurring closer to Big

Pine Key. Results indicated that other islands and complexes such as Ramrod Key, Water Key, and the Annette complex maintain only small sub-populations (e.g., ≤5 individuals) and other previously inhabited island complexes (i.e., Johnson complex and Summerland Key) no longer maintain sub-populations. Additionally, I compared abundance estimates from FLIR-based surveys to camera-based estimates. Although no test of accuracy was possible, camera-based survey methods consistently produced higher estimates of Key deer abundance on outer islands. Results indicate that aerial FLIR-based survey methods may be unreliable for the survey of large mammals in tropical habitats or areas exhibiting dense vegetation, and camera-based surveys should be the preferred method to survey Key deer abundance on outer islands.

DEDICATION

For my father, mother, and brother.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

This chapter provides a general outline of my thesis including background information and a breif review of research objectives. My thesis consists of 2 primary chapters (i.e., Chapter II and Chapter III). Each of these chapters represents an independent, but related, research paper and a reasonable amount of repetition should be expected among chapters. Chapter IV provides conclusions and management implications of the research presented in my thesis.

BACKGROUND

The Florida Key deer (*Odocoileus virginianus clavium*) was listed as an endangered species by the United States Fish and Wildlife Service (USFWS) in 1967. Key deer are endemic to the Florida Keys, where historic range likely extended from Key Vaca to Key West (Klimstra et al. 1978). Current Key deer distribution is restricted to the Lower Florida Keys, where deer inhabit approximately 20–25 islands from the Johnson keys to Sugarloaf Key. The majority of these islands are contained within the boundaries of the National Key Deer and Great White Heron National Wildlife refuges (Klimstra et al. 1974, Folk 1991, Lopez 2001).

By the late 1940s, habitat loss and unrestricted harvest had reduced the Key deer population to a roughly estimated 25–50 individuals (Dickson 1955). A cartoon drawn by Jay "Ding" Darling in 1934 was instrumental in acquiring national attention and legislation to protect Key deer. The establishment of the National Key Deer Refuge

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Format and style follows The Journal of Wildlife Management

(1957), curtailment of illegal hunting, and improved habitat conservation on Big Pine

and No Name keys allowed the population on these 2 islands to increase to an estimated

300–400 individuals by 1974 (Klimstra et al. 1974). The population continued to

increase, growing by approximately 240% between 1971 and 2001 (Lopez et al. 2004).

An estimated 75% of the current Key deer population resides on Big Pine and No Name

keys with the remaining deer distributed throughout the outer islands in small local sub-

populations where information regarding Key deer is lacking (Lopez 2001). In my

thesis, I refer to all islands within the known distribution of Key deer, excluding Big

Pine and No Name keys, as outer islands.

In metapopulation theory, landscapes are viewed as networks of habitat

fragments where local sub-populations exist and are connected by dispersal (Levins

1969, Hanski and Simberloff 1997, Meffe and Carroll 1997, Hanski 1998).

Consequently, metapopulation theory is useful when describing Key deer ecology as this

subspecies literally occupies a network of oceanic islands linked by dispersal (Lopez

2001). Dispersal is crucial to the stability and persistence of local sub-populations by

decreasing extinction risk through re-colonization (Akcakaya 2000). The spatial

arrangement and isolation of habitat patches influence despersal rates (Harrison et al.

1988, Kindvall and Ahlén 1992, Hanski et al. 1995, Stith et al. 1996, South 1999).

Dispersal rates also are influenced by population density and often exhibit a positive

correlation with increasing population density at source populations (Albon et al. 1992).

Studies have demonstrated density dependence in white-tailed deer populations

(McCullough 1979, Halls 1984) and analysis of abomasal parasite counts suggest that

Key deer on Big Pine and No Name keys are at or near carrying capacity (Nettles et al.

2001). Thus, outer islands, particularly those close to Big Pine Key, are likely to

experience increased immigration. Hanski (1998) concluded that the persistence of

metapopulations is influenced by the number of sub-populations present. The size and

composition of sub-populaitons also can greatly influence their persistence (May 1973,

1974, Schoener and Spiller 1987, Pimm et al. 1988, Hanski et al. 1994) with smaller

sub-populations exhibiting an increased probability of extinction due to factors such as

environmental and demographic stochasticity (Caughley 1994). Carrying capacity,

habitat characteristics, and juxtaposition in relation to source populations vary

considerably among outer islands (Lopez 2001, Harvison et al. 2006). Thus, it is

unlikely that the distribution and abundance of Key deer in these areas is spatially or

temporally constant, but likely varies with dispersal rates, habitat changes, and the

availability of suitable drinking water. Model-based research by Harveson et al. (2006)

provides insight into colonization rates on outer islands and Key deer metapopulation

dynamics.

Status assessments are compulsory to efficacious management of large mammal

populations, particularly for endangered species such as the Florida Key deer. However,

a dearth of data regarding these basic demographic parameters has limited status

assessment and management of Key deer on outer islands. Information regarding the

spatial distribution, abundance, and population trends of Key deer on outer islands is

necessary for current status assessment and continued management of this endangered

species. Traditional survey techniques for Key deer on Big Pine and No Name keys

include road-counts, strip-counts, and mark-recapture methods (Silvy 1975, Lopez 2001,

Roberts et al. 2006). However, practical limitations (e.g., dense foliage, lack of roads,

remote locations, etc.) render traditional survey techniques impractical for application on

outer islands. In addition, these methods can be labor-intensive, incur significant

financial costs, and may be subject to significant bias (Lancia et al. 1994, Jacobson et al.

1997, Roberts et al. 2006). Application of radio-telemetry methodology (White and

Garrott 1990) to estimate Key deer abundance is inhibited by the high cost and effort

associated with conducting these methods on outer islands. Other commonly applied

methods to estimate abundance of large mammals, such as track and fecal pellet counts

(Neff 1968, Fuller 1991), are likely to produce dubious abundance estimates as a result

of numerous confounding factors in the study area including low detection probabilities

and low deer densities. Thus, assessment of current status and appropriate management

of Key deer on outer islands is limited by a paucity of information regarding Key deer in

these areas.

RESEARCH OBJECTIVES

The overall objective of my study was to obtain baseline data regarding the

current distribution and abundance of Key deer inhabiting outer islands and to evaluate

the efficacy of contemporary survey techniques to obtain this information. My study

addressed 2 primary recovery and restoration actions identified in the South Florida

Multi-Species Recover Plan (USFWS 1999):

1. Develop method to survey deer on outer keys where conventional methods (i.e. spotlight counts) are difficult to implement. Obtain current deer density estimates for each island complex (USFWS 1999).

2. Establish a standardized method for future monitoring. Ideally, recommended survey techniques would be easy to apply, cost effective, and detect biologically significant changes in Key deer densities (USFWS 1999).

Data from this study will facilitate appropriate management and conservation of endangered Key deer throughout their range. Additionally, this information will be useful to the USFWS during status assessment and evaluation of the proposed re-classification of Key deer from endangered to threatened.

CHAPTER II

ABUNDANCE AND CURRENT DISTRIBUTION OF ENDANGERED KEY

DEER ON OUTER ISLANDS

SYNOPSIS

Status assessments are compulsory to efficacious management of large mammal

populations, particularly for endangered species such as the Florida Key deer.

Assessment of current status and appropriate management of Key deer is limited by a

paucity of information regarding Key deer on outer islands. Traditional survey

techniques for Key deer on Big Pine and No Name keys include road-counts, strip-

counts, and mark-recapture methods. However, practical limitations and financial

considerations render traditional survey techniques impractical for application on outer

islands. Infrared-triggered cameras may provide a practical alternative to estimate Key

deer abundance and monitor population trends on these islands. I used digital infrared-

triggered cameras to estimate Key deer abundance on 20 outer islands using natural

marks (e.g., antler configuration) to identify individual males. These individuals served

as a marked subset of the sub-population on their respective islands. I compared 3

frequently applied methods to estimate abundance from camera-based survey data.

Abundance estimates for primary natural sub-populations ranged from 15–16 for Howe

Key, 5–10 for Knockemdown complex, and 13–17 for Little Pine Key. Differences

among abundance estimators became more pronounced for sub-populations such as

Newfound Harbor complex (36–150) where model assumptions were violated. Results

indicate that other islands and complexes such as Ramrod Key, Water Key, and the

Annette complex maintain only small sub-populations (e.g., ≤5 individuals) and other

previously inhabited island complexes (e.g., Johnson complex and Summerland Key) no

longer maintain sub-populations. All outer islands exhibited Key deer abundances well

below carrying capacities estimated by Lopez (2001), with larger populations occurring

closer to Big Pine Key. Examination of relative abundance among islands raises

questions as to the factors which may be limiting Key deer densities in these areas.

Although no test of accuracy was possible, camera-based survey methods produced

reasonable estimates of Key deer abundance on outer islands when model assumptions

were not perceptibly violated. However, sub-population estimates using camera-based

survey methods may be subject to inherent biases associated with small sample sizes and

behavioral characteristics of individual Key deer. Managers should be cognizant of

potential biases and these estimates should be used with prudence in management and

status assessment of Key deer.

INTRODUCTION

The endangered Florida Key deer (*Odocoileus virginianus clavium*), the smallest

subspecies of North American white-tailed deer, is endemic to the Lower Florida Keys

(Lopez 2001). Key deer exhibit a restricted distribution within a highly fragmented

landscape consisting of 20–25 small oceanic islands. Big Pine Key (2,428 ha) is the

largest of the Lower Keys and is the core of the Key deer range (Lopez 2001, Harveson

et al. 2006). An estimated 75% of the total population resides on Big Pine and No Name

keys, with the remaining deer inhabiting outer islands which vary considerably in size

and habitat quality (Lopez 2001). Hereafter, I refer to all islands within the distribution

of Key deer, excluding Big Pine and No Name keys, as outer islands.

Information regarding the spatial distribution and population trends of Key deer

on outer islands is necessary for status assessment and appropriate management.

However, status assessment and appropriate management are currently limited by a

paucity of information regarding Key deer abundance and demographic structure on

outer islands. Estimation of Key deer abundance on outer islands is challenging due to

several confounding factors: (1) Key deer inhabiting outer islands are secretive and

difficult to observe; (2) outer islands exhibit dense tropical vegetation that severely

limits methods based on direct observation; (3) outer islands lack urban infrastructure

(e.g., road systems) and many are completely devoid of roads, being accessible only by

boat; (4) collection and analysis of quantitative data is problematic as sub-populations

occupying outer islands are small yielding small sample sizes; and, (5) trapping to

facilitate traditional mark-resight techniques is likely to be expensive and labor

intensive.

Traditional survey techniques for Key deer on Big Pine and No Name keys

include road-counts, strip-counts, and mark-recapture methods (Silvy 1975, Lopez 2001,

Roberts et al. 2006). However, practical limitations and financial considerations render

traditional survey techniques impractical for application on outer islands. Also, Roberts

et al. (2006) concluded that traditional techniques (e.g., road counts) used on Big Pine

and No Name keys are subject to biases associated with convenience sampling and

behavior of Key deer along roadways. Application of radio-telemetry methods to

estimate abundance of large mammals (White and Garrott 1990) is inhibited by the high

cost and effort associated with the application of these methods on outer islands. Other

potential estimation techniques for outer islands such as track and fecal pellet counts

(Neff 1968, Fuller 1991) are likely to produce dubious abundance estimates as a result of

numerous confounding factors in the study area including low detection probabilities and

low deer densities.

Infrared-triggered cameras may provide a practical and accurate alternative to

estimate Key deer abundance and monitor population trends on outer islands. Infrared-

triggered cameras have been used widely in wildlife research and management. Camera-

based surveys have been used to detect and monitor occupancy of rare mammalian

species in remote locations (Bull et al. 1992, Foster and Humphrey 1995, Kucera et al.

1995, Foresman and Pearson 1998), and to estimate abundance of rare or illusive large

mammals (Mace et al. 1994, Karanth and Nichols 1998, Sweitzer et al. 2000, Martorello

et al. 2003, Silver et al. 2004). Camera-based surveys have also been used to survey

large mammals in densely vegetated habitats where visual observation is inadequate to

facilitate traditional survey methods (Seydack 1984, Karanth and Nichols 1998, Carbon

et al. 2001). The purpose of my study was to evaluate the utility of camera-based

surveys to monitor occupancy and abundance of Key deer on outer islands and obtain

baseline information regarding the current distribution and abundance of Key deer in

these areas. In addition, I wanted to further evaluate the advantages and disadvantages

inherent in using baited camera-stations to estimate abundance of large mammal

populations (Mace et al. 1994, Jacobson et al. 1997, Koerth et al. 1997).

STUDY AREA

The study area is located in the Lower Florida Keys, Monroe County, Florida, USA. It encompasses all islands within the known distribution of Key deer, the majority of which are contained within the boundaries of the National Key Deer and Great White Heron National Wildlife refuges. Local geology is dominated by 2 Pleistocene formations: Miami limestone (oolite) and older Key Largo limestone below (Hoffmeister and Multer 1968, Halley et al. 1997). Topographic relief is extremely low and most islands are nearly flat with elevations <2 m. Soils vary from exposed oolitic bedrock to marl deposits and peat (Dickson 1955). Climate is subtropical marine with mean January temperatures of 21°C, mean July temperatures of 29°C, and average annual rainfall of 98.8 cm (National Oceanic and Atmospheric Administration data, 2006). Rainfall is highly seasonal, generally consisting of a 5 month wet season from late May to October, and a long dry season from November through May. Scattered thunderstorms and tropical storms are responsible for wet season precipitation.

Island complexes are groups of islands in close proximity to one another separated by shallow waters which can be functionally considered a single island (Folk 1992, Harveson et al. 2006). Klimstra et al. (1974) identified 15 island complexes where Key deer dispersal is relatively unrestricted and observed Key deer or their sign (e.g. tracks, pellets, evidence of browsing) on all 15 complexes. My research occurred on the same 15 island complexes, primarily on the following outer islands and island complexes: Annette complex, Big Torch Key, Cudjoe Key, Howe Key, Johnson complex, Knockemdown complex, Little Pine Key, Little Torch Key, Middle Torch

Key, Newfound Harbor complex, Ramrod Key, Sugarloaf Key, Summerland Key, and

Water Key (Figure 2.1).

Vegetation is principally West Indian in origin (Dickson 1955, Long 1974) and is

greatly influenced by elevation (Folk 1991, Lopez 2001). Vegetative communities near

sea level are primarily comprised of black mangrove (*Avicennia germinans*), white

mangrove (*Laguncularia racemosa*), red mangrove (*Rhizophora mangle*) and other

halophytes, which are successively replaced by buttonwood (*Conocarpus erectus*),

hammock, and pineland communities with increasing elevation (Lopez 2001). Outer

islands typically exhibit dense tropical vegetation which considerably impedes visibility

and movement in these areas. Lopez (2001) reported Key deer on Big Pine Key used

upland habitats (i.e., pineland and hammock) and avoided lowland habitats (i.e.,

buttonwood and tidal areas). However, lowland habitat types occur at comparatively

higher proportions on outer islands and Key deer on these islands frequently use

buttonwood and seasonally tidal areas (unpublished data). Key deer habitat on outer

islands was defined as pineland, hammock, buttonwood forest, seasonally tidal, and

developed areas (i.e., all available habitat excluding continually tidal areas).
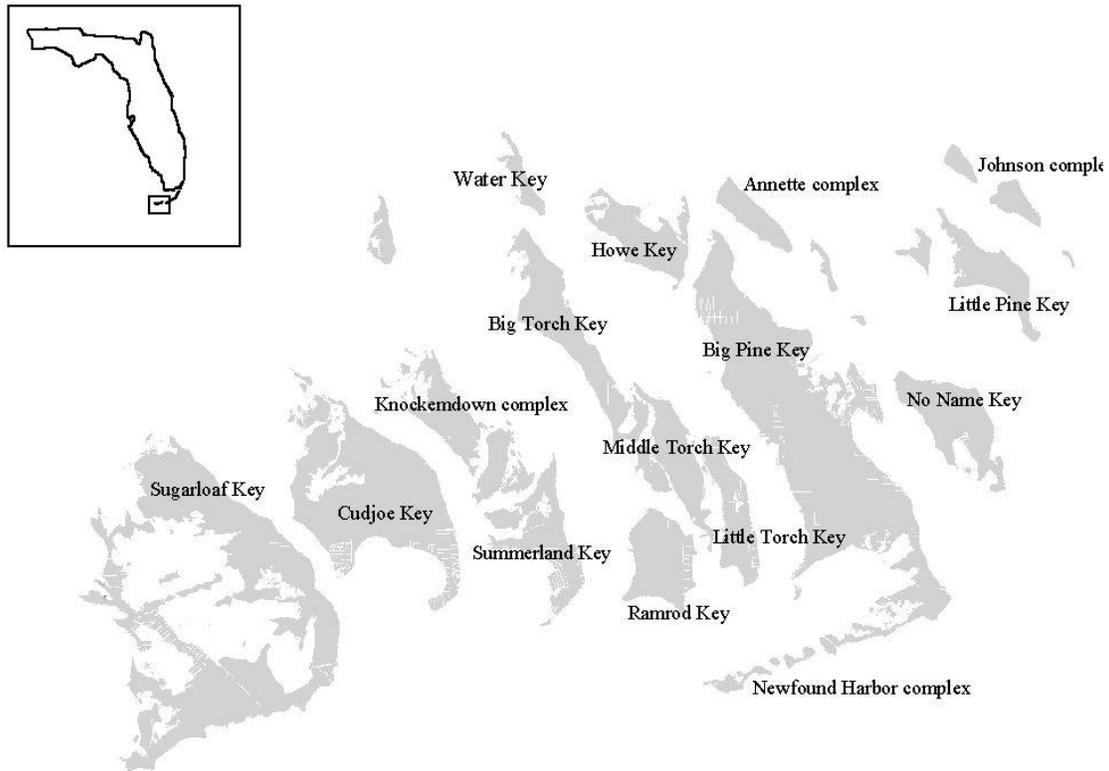
Figure 2.1. Map of the Lower Florida Keys, Florida, USA, including all islands within the known distribution of the endangered Florida Key deer.

METHODS

Data Collection

Klimstra et al. (1974) recorded observations of Key deer or their sign on outer islands and this information served as a basis for comparisons of Key deer distribution. Regular exploratory treks were conducted on all outer islands to examine the current distribution of Key deer. Islands were intensively searched for indications of Key deer presence (e.g., tracks, pellets, etc.) and areas of high use (e.g., trails, waterholes, etc.).

Presence or absence of Key deer sign was recorded for each survey unit to provide

distribution data for comparison with historic island occupancy.

Silvy (1975) reported seasonal ranges of Key deer to be 79–275 ha prior to

considerable urbanization on Big Pine Key and No Name keys. Lopez (2001) reported

significantly smaller seasonal ranges for Key deer (males: 102–309 ha, females: 36–112

ha) and suggested that seasonal ranges of Key deer have decreased as a result of

urbanization and domestication on these 2 islands. However, outer islands have

undergone comparatively less urbanization, and I suggest that Key deer inhabiting these

areas are likely to exhibit seasonal ranges similar to pre-urbanization ranges observed by

Silvy (1975).

Total Key deer habitat on island complexes was overlaid with a 50-ha grid to

generate ≤50 ha survey units. Camera-stations were placed at a density of 1 camera

station per survey unit. Assuming seasonal ranges comparable to those observed by

Silvy (1975), camera density provided approximately 1.5–5.5 camera-stations per Key

deer home range and offered complete coverage of Key deer habitat on each island

complex. A minimum of 2 camera-stations were placed on each complex to account for

long narrow islands or complexes consisting of several small islands. Preliminary

testing indicated that placement of camera-stations in areas of high use was crucial to

acquiring sufficient photographic captures of Key deer. Camera-stations were

subjectively placed within sample units at sources of freshwater, along trails, in areas

where Key deer or their sign were observed, or along likely travel corridors when no

presence was detected. Camera-stations were baited once during setup with ≤3.8 l of

domestic feed (e.g., sweet feed or cracked corn) to entice exploration by Key deer

passing in close proximity to the camera-station and maximize photographic captures.

Camera-stations were not re-baited and bait was spread sparsely over a large area (50–

100 m^2) around the camera station.

Camera-stations were operated simultaneously on each island complex for 20

consecutive 24-hour periods (days). Commercially available Cuddeback digital

infrared-triggered cameras (Non-typical Inc., Park Falls, Wisconsin, USA) were used to

photograph Key deer. This system is a self-contained digital camera utilizing a passive

infrared sensor. Cameras were mounted on vegetation or constructed platforms

approximately 30 cm above ground and set to manufacturer-recommended settings for

local environmental conditions. Picture delay was set to 1 minute and video mode was

used to record 10–20 seconds of video after the initial photograph. Video was used to

increase accuracy during identification of individuals and to document neonates which

might not be recorded in initial photographs. Date and time were automatically recorded

on each digital photograph.

Data Analysis

Digital photographs were scrutinized to identify individual Key deer by antler

configuration. Preliminary data indicated that marked individuals lingered at recently

baited camera-stations a maximum of 47 minutes. Multiple photographs of

indistinguishable deer within a ≤1-hour period at a single camera-station were excluded

during analysis to minimize double-counting animals. Thus, valid photographic captures

were identified and individually identifiable adult male Key deer served as marked

individuals. Photographic captures were grouped into 4 categories (Jacobson et al. 1997): (1) individually identifiable adult males, (2) adult females, (3) indistinguishable antlered males (e.g., spikes), and (4) sub-adults. Valid captures were calculated separately for each camera-station and pooled for each island complex. In addition to adult males, collared females from a concurrent study on Cudjoe and Sugarloaf keys served as marked females for analysis of sightability. However, collared females were treated as un-marked adult females during calculation of sub-population abundance.

Using the same 20-day survey data, 3 frequently used methods to calculate abundance from camera surveys were compared. Methods described by Jacobson et al. (1997) were used to calculate abundance estimates for a 20-day survey period. A 2-sample Peterson model (Seber 1982) was used to calculate a second abundance estimate using a 10-day mark and 10-day re-sight period. Baily's binomial model (Bailey 1952) was used as it is more robust to small sample sizes (Seber 1982). Resultant abundance estimates were then fit to a Poisson distribution and simulations were used to develop corrected population estimates using sightability of known deer on Cudjoe and Sugarloaf keys (70–100%). Finally, a third abundance estimate was obtained using methods developed by Minta and Mangel (1989) which uses the capture frequencies of marked individuals to estimate capture frequencies of non-marked individuals by means of bootstrap methods. Minta-Mangel estimates were calculated using Program NOREMARK (White 1996). Lower bounds of confidence intervals were adjusted to account for the minimum number known alive on each island complex where applicable, and all fractions were rounded up to the nearest whole number.

Total sampling effort was defined as the sum of all 24-hour periods (days) cameras were operated on an island complex. Photographic capture rate was defined as the number of valid photographic captures of Key deer per day summed for all camera stations on an island complex. Catch per unit effort (CPUE) was defined as C/X, where C is the total valid photographic captures and X is the total sampling effort for each island complex.

Model Assumptions

Methods developed by Jacobson et al. (1997) are solely designed to estimate population size and rely heavily on closure assumptions. The Peterson model also relies heavily on assumptions of geographic and demographic closure. Using methods presented here it is difficult to formally address closure assumptions. However, geographic closure can reasonably be assumed as individual islands represent functionally closed island populations during the survey period and entire island complexes were sampled simultaneously. The short duration of the total survey (i.e., 20 days) reasonably satisfies demographic closure assumptions and also allows the assumption of mark retention for the entirety of the survey. The use of cameras also allows assumption of little or no disturbance to natural activities which are commonly associated with live-capture studies. When estimating the density of animals in an area, studies typically add a boundary strip to the area defined by grids in order to account for captured animals that commonly occur outside the grid area (Otis et al. 1978, White et al. 1982). However, this method was not applied as I assume complete camera coverage of Key deer habitat on each island complex.

Sightability in any sample is a function of an individual animal and varies over the population according to sex, age, and other factors (Pollock 1982, White et al. 1982). Model assumptions such as equal sightability among all individuals, independence of sightings, and population closure are rarely met in toto (Arnason et al. 1991) and studies using photographs to obtain information regarding abundance commonly assume equal detectability among individuals (Cutler and Swann 1999). Baiting may introduce bias which affects the accuracy and precision of abundance estimates (White et al. 1982). Cumulative photographic capture rate was examined to test for bait induced bias.

It is impossible to test the assumption of equal sightability among survey periods using a 2-sample Peterson model with any statistical power (Krebs 1999). Sighting histories were developed for all individually identifiable Key deer on outer islands using each day as a sampling period (n =20). The assumption of equal sightability of Key deer by day was tested using a Zero-Truncated Poisson Test for Equal Sightability (Caughley 1977). Expected values were derived from observed data and expected values <1.0 were amalgamated into a single category (i.e., $\geq$ 9 captures). A Chi-square goodness-of-fit test was conducted on these data to test the null hypothesis of equal sightability among Key deer by day. To evaluate sightability among sexes and the validity of using only males as marked individuals on outer islands, capture histories for individually identifiable males on all outer islands and collared females on Cudjoe and Sugarloaf keys were analyzed using Program MARK (White and Burnham 1999).

One method to improve the accuracy of abundance estimates is to replicate surveys (White and Garrott 1990). Practical limitations, the need to obtain baseline data

for all outer islands within the alloted timeframe of the study, and setbacks due to

hurricanes prohibited replication of surveys on individual islands. However, 2 surveys

were conducted on Sugarloaf Key to gain insight into the precision of camera-based

estimates of Key deer abundance.

RESULTS

Key deer or their sign were detected on 13 of 15 historically occupied island

complexes. In addition, Key deer presence was documented on Spanish Harbor Key.

No evidence of Key deer presence was detected on Summerland Key or Big Johnson

complex. Results of camera-based island occupancy surveys were equivalent to sign

surveys used by Klimstra et al. (1974). Additionally, cameras detected Key deer

presence in 2 survey units where sign surveys did not produce indications of presence.

Cameras obtained 649 valid photographic captures of Key deer on outer islands.

Sixteen of 19 (84.2%) known individually identifiable Key deer inhabiting outer islands

were photographically captured by Day 10. Seventy percent of known Key deer on

Sugarloaf and 100% of known deer on Cudjoe were photographically captured by Day

10. Cumulative capture rate for new individually identifiable Key deer reached

asymptote around Day 9 and only 2 previously unidentified Key deer were captured after

day 10 (Fig. 2.2). One of 2 new marked deer appearing after Day 10 was likely to have

immigrated from south Big Pine Key to Newfound Harbor complex. Individually

identifiable ('marked') Key deer were regularly captured throughout the 20-day survey

period at multiple camera stations. Mean capture of 'marked' individuals during re-

capture sessions was 2.7 and 2.4 for males and females respectively. Number of re-captures for individual 'marked' Key deer ranged from 1–7. Results of Zero-Truncated Poisson Tests of Equal Sightability indicated that sightability by day was not equal among all individual marked Key deer ($P <0.001$). Results of model selection using Program MARK indicated no significant difference in sighting probabilities by day between sexes (male = 0.244, SE = 0.031; female = 0.224, SE = 0.019).
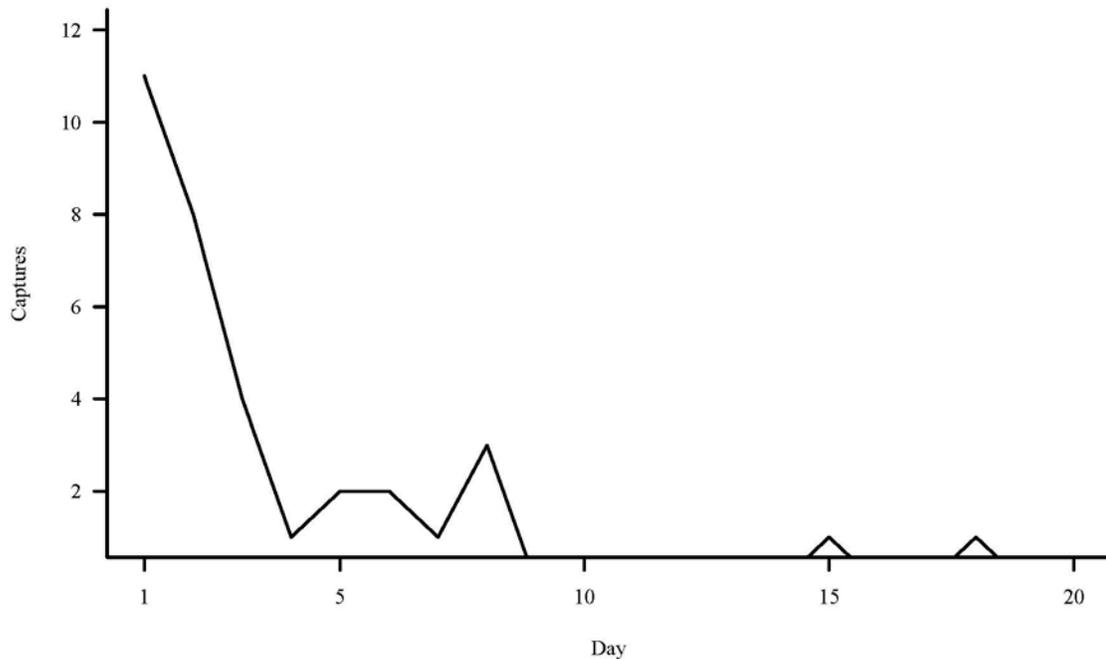
Figure 2.2. Number of previously unrecorded individually identifiable Key deer (y-axis) captured by day using digital infrared-triggered cameras on outer islands, Lower Florida Keys, Florida, USA, 2005.

Estimated abundance and density of Key deer varied considerably among outer islands (Table 2.1). Absence of mature males on several islands prohibited calculation of abundance. For these island complexes, the minimum number known alive should be considered a conservative sub-population estimate and these sub-populations are assumed to consist of ≤ 5 individuals. The Peterson estimator produced negatively biased pre-adjustment estimates (i.e., below MNKA) on Cudjoe Key due to 'trap-happy' male Key deer. Conversely, estimators may have over-estimated abundance on Newfound Harbor complex. Bias was likely due to violations of closure assumptions, 'trap-shy' marked individuals during re-capture sessions, an unusually high density of Key deer due to proximity to Big Pine Key, and anthropogenic factors described in more detail below.

Cumulative capture rate indicated baiting had a considerable effect on the number of photographic captures of Key deer (Fig. 2.3). Photographic captures were highest during the first 2–4 days of each survey and declined considerably until becoming more stable around 5–6 days. Newfound Harbor complex was excluded from cumulative results for several reasons: (1) Newfound Harbor complex is a primary dispersal area for south Big Pine Key, (2) Newfound Harbor has an unusually high density of Key deer due to anthropomorphic factors (e.g. camp grounds, ornamental plants), and (3) Newfound Harbor is used as a corridor to Little Palm Island where Key deer feed on ornamental plants, utilize freshwater resources, and are regularly fed by island occupants.

Table 2.1. Estimated abundance of Key deer sub-populations on outer islands, Lower

Florida Keys, Florida, USA, 2005, derived from digital infrared-triggered camera data.

Island complex	Area (ha)	Jacobson estimate	Peterson estimate (adjusted)	Minta-Mangal estimate	MNKA[a]	CPUE[b]
Annette complex	222	NC[c]	NC[c]	NC[c]	1	0.05
Cudjoe	1,319	9	8	11	7	0.99
Howe	373	15	16	16	9	1.80
Johnson complex	154	0	0	0	0	0.00
Knockemdown complex	582	5	9	10	3	0.27
Little Pine	381	17	12	13	4	0.67
Newfound Harbor complex	76	36	93	150	6	4.15
Ramrod	374	NC[c]	NC[c]	NC[c]	1	0.35
Sugarloaf (survey 1)	1,399	27	22	69	5	0.59
Sugarloaf (survey 2)	1,399	23	30	25	5	0.64
Summerland	436	0	0	0	0	0.00
Big Torch	626	17	29	NC[a]	4	0.17
Little Torch	305	8	5	NC[a]	3	0.20
Middle Torch	410	3	4	3	3	0.05
Water	92	NC[c]	NC[c]	NC[c]	1	0.10

[a] MNKA, absolute minimum number of individual Key known to be alive during survey.
[b] CPUE (catch per unit effort), defined as the total number of valid photographic captures divided by the total number of camera days (i.e., number of cameras multiplied by 20 days).
[c] NC, estimate was not calculable due to insufficient captures of individually identifiable Key deer during capture or re-capture periods.
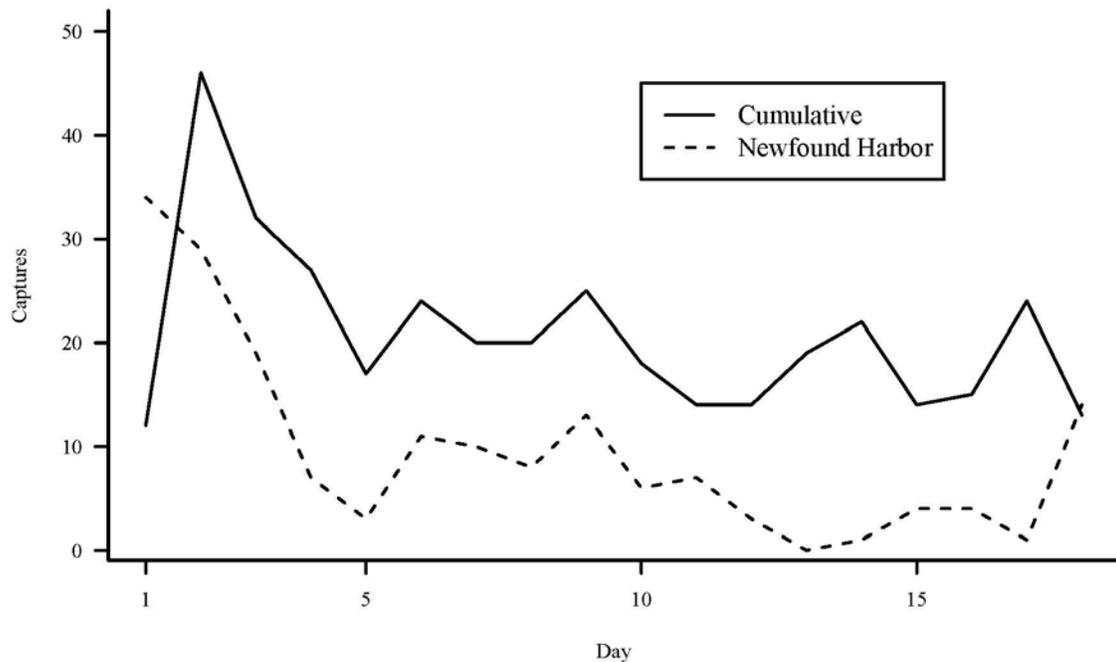
Figure 2.3. Cumulative capture rate for Key deer on all outer islands (excluding

Newfound Harbor complex) and Newfound Harbor complex using digital infrared-

triggered cameras, Lower Florida Keys, Florida, USA, 2005.

DISCUSSION

Jacobson et al. (1997) reported 100% and 88% of known deer were

photographically captured during a 14-day period and 100% and 82.3% where captured

during the first 10 days of the survey. Similar results during this study (84.2% by Day

10), observed cumulative photographic capture rate of new individuals, and

photographic captures of marked deer at multiple camera stations indicate that the

majority of Key deer inhabiting outer islands were recurrently photographically

captured. Thus, camera density on islands appears to have been sufficient. Higher

camera density might result in capture of all individuals but may not be practical. Data

analysis also indicated closure assumptions were reasonably met. Misidentification of

individuals during analysis, particularly marked individuals, could potentially bias

survey results. However, marked individuals in this study offered distinctly

recognizable characteristics which permitted accurate identification during analysis.

Karanth (1995), Jacobson et al. (1997) and Koerth (1997) noted that

heterogeneous sightability of different age and sex classes could bias abundance

estimates based on photographic data. Tests of equal sightability by survey period (i.e.

10 days) could not be conducted with any statistical power. However, results of Zero-

Truncated Poisson Test of Equal Sightability indicated that sightability of Key deer by

day was heterogeneous among individuals. Although it is difficult to relate sightability

by day to sightability by survey period (10 days), these results indicate model

assumptions of homogeneous sightability among individuals may have been violated.

However, the mean number of captures during re-capture sessions (males: 2.7, females:

2.4) and results of model selection using Program MARK indicate sightability of Key

deer is not a function of sex. Equivalent detection probabilities between sexes indicated

the use of male Key deer as marked individuals in sub-populations is permissible, thus,

minimizing the need for expensive and labor intensive capture operations.

Baiting offered advantages and disadvantages to camera-based surveys and the

effects of baiting should be thoroughly examined prior to implementation of camera-

based surveys. Jacobson et al. (1997) and Koerth et al. (1997) used bait at camera

stations to increase photographic captures of white-tailed deer. However, the Jacobson

estimator relies heavily on assumptions of equal sightability among all individuals

throughout the survey period (e.g., 20 days in this study). A decline in cumulative

capture rate indicated baiting affected sightability of Key deer through the survey period.

Bias associated with heterogeneous sightability among all individuals is likely to be

exacerbated as "trap-happy" individuals could significantly influence results if camera

stations are regularly baited. Thus, baiting should not be employed when collecting data

for use with methods described by Jacobson et al. (1997). Another possible method to

minimize the effects of baiting using the Jacobson estimator would be to exclude the

period where influence of bait was most significant (e.g., Days 1–5 in this study).

Conversely, the 2-sample Peterson model is not affected by differential sightability

between marking and re-sighting sessions provided that sightability is homogeneous

within the re-sight session and observation in the first session is independent of

observation in the second. Cumulative capture rates indicated the effects of baiting Key

deer dissipated by Day 5 allowing increased captures during 'marking' periods (i.e.,

increased marked individuals) without violating model assumptions.

Three frequently applied methods to estimate abundance from camera-based

survey data were compared in this study. All 3 estimators produced reasonable results

(i.e., compared to sign observed) when model assumptions were not perceptively

violated. However, abundance estimators produced spurious results for sub-populations

where assumptions of homogeneous sightability were violated. Islands such as

Newfound Harbor complex were likely biased high due to low sightability of 'marked'

Key deer during re-capture sessions and violations of closure assumptions. Conversely,

on Cudjoe Key, 2 males were captured on as many as 5–7 occasions during the 10-day

recapture session whereas other 'marked' Key deer were typically captured on 2–3

occasions during this same time period. Thus, estimates of abundance on Cudjoe Key

would be expected to be negatively biased. All 3 estimators used to develop abundance

estimates are subject to inherent biases associated with small samples sizes and

sightability of individual deer. Sightability of individual Key deer is an inherent

problem when estimating Key deer abundance using camera-based methods. Methods

developed by Minta and Mangel (1989) address variation in sightability among

individual Key deer and I recommend application of this method when estimating

abundance of Key deer on outer islands.

This study provides current information regarding the distribution and status of

Key deer inhabiting these areas. Data indicate the distribution of Key deer may have

constricted since the early 1970s. Absence of Key deer on previously occupied islands

such as Big Johnson and Summerland keys may be an indication of declines on outer

islands. Big Johnson likely serves as a sink or dispersal area for the sub-population on

Little Pine Key. Thus, the current absence of Key deer on Big Johnson Key is indicative

of sub-population declines on Little Pine Key and the same holds true for source

populations near Summerland and Ramrod keys. However, meta-populations are

dynamic and the absence or low density of Key deer on specific outer islands may be the

result of natural fluctuation in meta-population structure.

This study is the first effort to estimate abundance of Key deer sub-populations on outer islands. Model-based research by Harveson et al. (2006) concluded that distance from source populations and island size significantly effects Key deer abundance on outer islands, and the results of this study support their conclusions. Natural (i.e., excluding translocations) Key deer abundance was greatest on island complexes closest to Big Pine Key (e.g., Howe Key, Little Pine Key, and Big Torch). Estimates for other island complexes such as Ramrod Key, Water Key, and Annette complex indicate that these islands maintain only small sub-populations (i.e., ≤5 individuals) which are likely seasonal or ephemeral in nature. All outer islands, with the exception on Newfound Harbor complex, exhibited Key deer abundances well below carrying capacities estimated by Lopez (2001). The effects of recent hurricanes on vegetation and freshwater quality are possible explanations for the observed constriction of distribution and low abundances. Examination of relative abundance among outer islands raises questions as to the factors which may be limiting Key deer abundance in these areas. Islands such as Sugarloaf and Cudjoe have sufficient habitat and would be expected to maintain higher Key deer densities than were observed. It is important to note that estimates presented here include translocated Key deer on Cudjoe and Sugarloaf and natural Key deer numbers were likely low (≤5–10 individuals) prior to translocations. It is likely that Key deer naturally occur at densities below carrying capacity on outer islands and the high densities observed on Big Pine and No Name keys are the product of anthropogenic influence. However, primary factors effecting the

distribution and abundance of Key deer throughout their range (e.g., fresh water) warrant further investigation.

MANAGEMENT IMPLICATIONS

Reclassification of Key deer from endangered to threatened has recently been proposed as a result of increased Key deer densities at the core of their range (i.e., Big Pine and No Name keys; Lopez et al. 2004). Attempts to establish viable sub-populations (Parker 2006) address other recovery criteria regarding increased Key deer abundance on outer islands. Other recovery criteria such as evaluation of status and trends of Key deer on islands will also play an important role in the decision making process. Information from this study will be useful during evaluation of the proposed reclassification of Key deer. Data from this study also will facilitate appropriate management and conservation of the endangered Key deer throughout their range.

A primary concern of wildlife managers is the costs associated with the monitoring of wildlife populations. Use of natural markings is preferred to active-marking techniques for Key deer due to the temporal and financial costs associated with maintaining marked segments of sub-populations on 20–25 outer islands. Similar sightability among male and female Key deer and use of natural marks minimized temporal and financial costs associated with conducting surveys of abundance on outer islands. In addition, this method alleviates the need to capture and mark Key deer.

Use of digital infrared-triggered camera equipment offered several advantages over traditional film-operated systems. Roberts et al. (2006) reported that film-operated

camera surveys cost approximately $85 per week (11 cameras) excluding vehicle, fuel, and camera equipment. Comparatively, cost associated with operation of 11 digital cameras for up to 30 days is approximately $55 excluding boat, fuel, and equipment. Digital cameras also minimize disturbance to study subjects and significantly reduce trips in the field by requiring significantly less maintenance (e.g. changing film). This may be a significant advantage for diffident species such as large felids. In addition, digital systems can minimize data loss associated with loss of available film caused by non-target species as reported by Karanth (1995), Koerth et al. (1997), and Kawanishi (2002).

Digital camera-based surveys offer an accurate and practical method to monitor island and habitat occupancy, offering insight into the status and trends of Key deer throughout their range. Results indicate camera-based surveys may provide a practical method to monitor Key deer abundance and population trends on outer islands. In addition, camera-based surveys could provide a method to evaluate the efficacy of management actions on outer islands such as translocations and habitat manipulation. However, sub-population estimates may be subject to inherent bias associated with small sample sizes and behavioral characteristics of individual Key deer. Differences between the 2 surveys conducted on Sugarloaf Key suggest it may be advantageous to conduct multiple surveys to address the precision of abundance estimates. Managers should be cognizant of potential biases and sub-population estimates should be used with prudence in management of Key deer. Further validation of camera-based surveys is desirable.

CHAPTER III

COMPARISON OF INFRARED-TRIGGERED CAMERAS AND AERIAL

THERMAL-IMAGING TO ESTIMATE ABUNDANCE OF ENDANGERED KEY

DEER ON OUTER ISLANDS

SYNOPSIS

Status assessments are compulsory to efficacious management of large mammal populations, particularly for endangered species such as the Florida Key deer. Assessment of current status and appropriate management of Key deer is limited by a paucity of information regarding Key deer on outer islands. Traditional survey techniques for Key deer include road-counts, strip-counts, and mark-recapture methods. However, practical limitations and financial considerations render traditional survey techniques impractical for application on outer islands. I compared surveys using forward looking infrared-thermography (FLIR) technology and digital infrared-triggered cameras to estimate Key deer abundance on outer islands. Utility of aerial FLIR-based surveys appears to be limited by low sightability due to dense tropical vegetation. Although no test of accuracy was possible, camera-based survey methods consistently produced higher estimates of Key deer abundance on outer islands. However, sub-population estimates using camera-based survey methods may be subject to biases associated with small sample sizes and behavioral characteristics of individual Key deer. Managers should be cognizant of potential biases inherent in methods to estimate abundance of Key deer on outer islands and these estimates should be used with prudence in management of this endangered species.

INTRODUCTION

The endangered Florida Key deer (*Odocoileus virginianus clavium*), the smallest subspecies of North American white-tailed deer, is endemic to the Lower Florida Keys. Key deer exhibit a restricted distribution within a highly fragmented landscape consisting of 20–25 small oceanic islands. Big Pine Key (2,428 ha) is the largest of the Lower Keys and is the core of the Key deer distribution (Lopez 2001, Harveson et al. 2006). Approximately 75% of the total population resides on Big Pine and No Name keys, with the remaining deer inhabiting outer islands which vary considerably in size and habitat characteristics (Lopez 2001). Here, I will refer to all islands within the Key deer range, excluding Big Pine and No Name keys, as outer islands. Information regarding the spatial distribution and population trends of Key deer on outer islands is necessary for status assessment and appropriate management. However, status assessment and appropriate management are currently limited by a paucity of information regarding Key deer on outer islands.

Traditional survey techniques for Key deer on Big Pine and No Name keys include road counts, strip counts, and mark-recapture methods (Silvy 1975, Lopez 2001, Roberts 2006). Practical limitations and financial considerations render traditional survey techniques impractical for application on outer islands. Additionally, Roberts et al. (2006) concluded that traditional survey methods are subject to bias derived from convenience sampling. Application of radio-telemetry methods to estimate Key deer abundance (Silvy 1975, Lopez 2001) is inhibited by the high cost and effort associated with conducting these methods on outer islands. Other potential estimation techniques

for outer islands, such as track and fecal pellet counts (Neff 1968, Fuller 1991), are likely to produce dubious abundance estimates as a result of numerous confounding factors in the study area including low detection probabilities and low deer densities. Infrared-triggered cameras have been used widely in wildlife research and management and may provide a practical method to monitor Key deer on outer islands. Accuracy of camera-based surveys may be subject to bias associated with small sample sizes and heterogeneous sightability among individual Key deer. In addition, camera-based surveys require approximately 21–30 days to complete per island complex and it may not be practical to survey all outer islands annually.

Forward-looking infrared thermography (FLIR) detects thermal radiation from objects and converts this radiation into visible images allowing differentiation between objects of different temperatures. Thus, FLIR technology can be used to detect the presence of large mammals which emit thermal radiation at higher intensity that background objects. Boonstra et al. (1994) gives a more detailed description of FLIR technology. Forward looking infrared-thermography technology has been used to survey large mammal populations (Croon et al. 1968, Havens and Sharp 1998, Wiggers and Beckerman 1993, Dunn et al. 2002) and may provide a practical and accurate alternative to estimate Key deer abundance and monitor population trends on outer islands. Primary sub-populations occur on Big Torch, Cudjoe, Howe, Little Pine, Big Knockemdown, Little Knockemdown, and Sugarloaf keys. However, many outer islands exhibit small Key deer sub-populations (e.g., ≤5 individuals) which are difficult to accurately estimate using camera-based surveys. FLIR-based surveys may provide an alternative method to

survey these small sub-populations accurately. Aerial FLIR-based surveys also could provide a temporally effective method to obtain sub-population estimates offering managers the ability to annually survey all outer islands and make status assessments immediately following natural disasters such as major hurricanes or disease outbreaks.

Limitations and local conditions may restrict the utility of FLIR for the survey of large mammals in tropical and sub-tropical conditions. Wyatt et al. (1980) indicated that surveys using thermal contrast alone may be insufficient for the survey of large mammals. Inadequate differences between ambient and biological temperatures can significantly limit aerial detection of large mammals using FLIR technology. Exposed ground and rocks, and thermal radiation from vegetation also may cause false detections and this problem may be exacerbated in warmer climates such as the tropics. Additionally, dense vegetation may limit the utility of FLIR technology for the survey of large mammals (Garner et al. 1995, Dunn et al. 2002), particularly in tropical and sub-tropical environments where dense vegetation is generally pervasive. FLIR technology has been most successfully applied in open vegetation types or controlled environments (Croon et al. 1968, Wiggers and Beckerman 1993, Naugle et al. 1996). Havens and Sharp (1998) reported positive results using FLIR to survey large mammal populations in wooded areas in southern Florida, USA. This study suggests FLIR-based surveys might provide a functional method to survey Key deer. The purpose of this study was to compare camera-based and FLIR-based methods to survey Key deer sub-populations on outer islands and further investigate the utility of FLIR in sub-tropical environments.

STUDY AREA

The study area is located in the Lower Florida Keys, Monroe County, Florida, USA. It encompasses all islands within the known distribution of Key deer, the majority of which are contained within the boundaries of the National Key Deer and Great White Heron National Wildlife refuges. Local geology is dominated by 2 Pleistocene formations: Miami limestone (oolite) and older Key Largo limestone below (Hoffmeister and Multer 1968, Halley et al. 1997). Topographic relief is extremely low and most islands are nearly flat with elevations <2 m. Soils vary from exposed oolitic bedrock to marl deposits and peat (Dickson 1955). Climate is subtropical marine with mean January temperatures of 21°C, mean July temperatures of 29°C, and average annual rainfall of 98.8 cm (National Oceanic and Atmospheric Administration data, 2006). Rainfall is highly seasonal, generally consisting of a five month wet season from late May to October, and a long dry season from November through May. Scattered thunderstorms and tropical storms are responsible for wet season precipitation.

Vegetation is principally West Indian in origin (Dickson 1955, Long 1974) and is greatly influenced by elevation (Folk 1991, Lopez 2001). Vegetative communities near sea level are primarily comprised of black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), red mangrove (*Rhizophora mangle*) and other halophytes, which are successively replaced by buttonwood (*Conocarpus erectus*), hammock, and pineland communities with increasing elevation (Lopez 2001). Outer islands typically exhibit dense tropical vegetation that considerably limits visibility and the applicability of traditional methods to survey large mammals (Lancia et al. 1994,

Jacobson et al. 1997, Jachmann 2002). Vegetation density is decreased in February

during leaf-off offering a period of increased visibility for aerial surveys. Lopez (2001)

reported Key deer on Big Pine Key used upland habitats (i.e., pineland and hammock)

and avoided lowland habitats (i.e., buttonwood and tidal areas). However, lowland

habitat types occur at comparatively higher proportions on outer islands and Key deer on

these islands frequently use buttonwood and seasonally tidal areas (unpublished data).

Key deer habitat on outer islands was defined as pineland, hammock, buttonwood forest,

seasonally tidal, and developed areas (i.e., all available habitat excluding continually
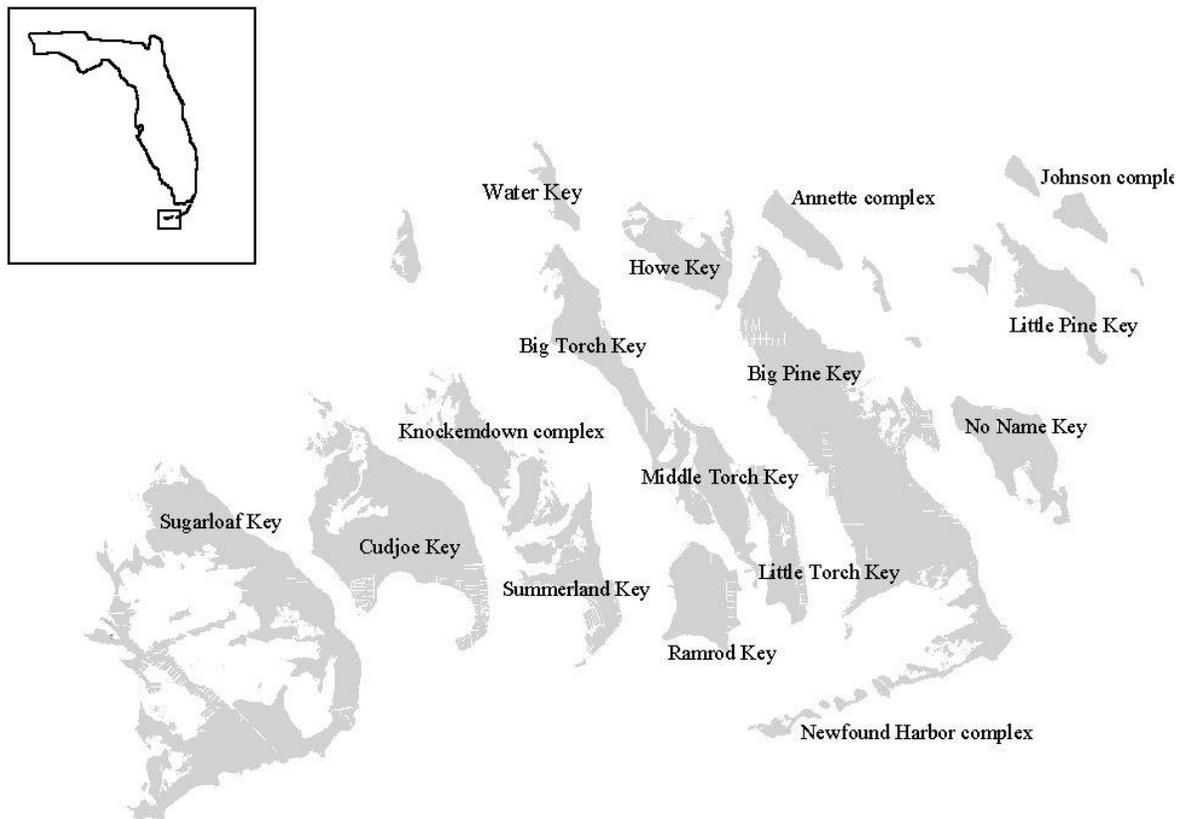
tidal areas).

Figure 3.1. Map of the Lower Florida Keys, Florida, USA, including all islands

within the known distribution of the endangered Florida Key deer.

METHODS

Aerial-FLIR Surveys

Aerial-FLIR surveys were conducted on from a Bell Ranger 206L-4 helicopter using a handheld ThermaCAM® B-20 (FLIR Systems, North Billerica, Massachusetts, USA) with a 24° lens. At least one survey was conducted on Annette complex, Cudjoe Key, Howe Key, Knockemdown complex, Little Pine Key, Knockemdown, Sugarloaf Key, Torch complex, and Water Key. Surveys were conducted during early morning to maximize thermal contrast between Key deer and background (Havens and Sharp 1998). Flights were conducted at an altitude of 90–100 m as preliminary tests indicated this elevation offered optimal FLIR ground-swath width without flushing Key deer and double counting (Naugle et al. 1996). The ThermaCAM® FLIR system provided a 24° x 18° field of view resulting in a ground swath approximately 28-m wide (vertical swath varied with camera pitch). North-south transects were flown at approximately 16–24 km/hour (9–13 knots) and transects offered complete coverage of islands. The FLIR unit was operated by an experienced observer during all preliminary testing and surveys. Observer door was removed and panning technique was employed to improve detection of deer in wooded areas and discrimination of large mammal species (Havens and Sharp 1998). Number and location of Key deer thermal signatures were recorded by a second observer in the helicopter. FLIR-based population estimates represent minimum counts of Key deer on their respective islands.

Camera-based Surveys

Island complexes were divided into 50-ha survey units and intensively searched

for indications of Key deer presence and areas of high use. Cameras were placed in

areas of high use at a density of 1 camera per survey unit. Assuming seasonal ranges

comparable to those observed by Silvy (1975), placement provided approximately 1.5–

5.5 camera units per Key deer home range and offered complete coverage of Key deer

habitat on each island complex. Commercially available Cuddeback digital infrared-

triggered cameras (Non-typical Inc., Park Falls, Wisconsin, USA) were used to

photograph Key deer. Camera density was 1 camera/sample unit (~50 ha) offering

complete coverage of Key deer habitat on each island complex. Cameras were

subjectively placed within sample units at sources of freshwater, along trails, in areas

where Key deer or their sign were observed, or along likely travel corridors. Camera-

stations were baited once at initial setup with $\leq$3.8 l of domestic feed (e.g., sweet feed,

cracked corn) to entice exploration by Key deer passing in close proximity to the camera

station and maximize captures of individually identifiable Key deer. Cameras were

operated simultaneously on each island complex for 20 consecutive 24-hour periods

(days). Date and time were automatically recorded on each digital photograph.

A 2-sample Peterson model (Seber 1982) was used to calculate abundance

estimates using a 10-day mark and 10-day re-sight period. Bailey's binomial model

(Bailey 1952) was used as it is more robust to small sample sizes (Seber 1982).

Resultant abundance estimates were then fit to a Poisson distribution and simulations

were used to develop corrected population estimates using sightability of known deer on

Cudjoe and Sugarloaf keys (70–100%). Lower bounds of confidence intervals were adjusted to account for the minimum number known alive on each island complex and all fractions were rounded to the nearest whole number. Sightability of Key deer using cameras was analyzed using Program MARK (White and Burnham 1999) and Zero-Truncated Poisson Test of Equal Sightability (Caughley 1977). For a more detailed discussion of camera surveys see Chapter II.

Camera-based surveys were completed in close temporal proximity to FLIR surveys and I assume demographic and geographic closure between camera-based and FLIR-based surveys. Observed dispersal, movements, and mortality factors of Key deer on Big Pine Key (Lopez 2001, Lopez et al. 2003) support this assumption. Closure assumptions were further supported by monthly survival rates and locations of radio-collared Key deer on Cudjoe and Sugarloaf during this timeframe (100%; Parker 2006).

RESULTS

Aerial-FLIR surveys occurred on 28 February-March 1, 2005 and 9–10 February, 2006 between 0630 and 0900 hours. Total area surveyed was approximately 3,472 ha yielding a total of 26 thermal signatures of Key deer in 2005 and 4,076 ha yielding a total of 27 thermal signatures in 2006. Temperatures ranged from 15–24°C during surveys and were within the limitations of the FLIR system. Key deer thermal signatures were clearly visible and distinguishable under local conditions when Key deer were located in open areas. However, thermal signatures were more difficult to detect in dense vegetation. Aerial-FLIR surveys recorded 4 thermal signatures of Key deer on

Cudjoe where an absolute minimum of 7 deer were known to be present during the 2005

survey. Similarly, 7 thermal signatures of Key deer were recorded on Sugarloaf in 2005

and 6 thermal signatures in 2006 where an absolute minimum of 12 Key deer were

known to be present during surveys. Cudjoe was not surveyed in 2006 due to flight zone

restrictions.

Cameras obtained 649 valid photographic captures of Key deer on outer islands.

Sixteen of 19 (84.2%) known individually identifiable Key deer inhabiting outer islands

were photographically captured in 2005–2006. Cumulative capture rate for new

individually identifiable deer reached asymptote around Day 9 and only 2 previously

unidentified deer were captured after Day 10. Marked Key deer were regularly captured

throughout the 20-day survey period at multiple camera stations. Mean capture of

marked individuals during re-capture sessions was 2.7 and 2.4 for males and females

respectively. Number of captures for individual marked Key deer ranged from 1–7

captures and results of Zero-Truncated Poisson Test of Equal Sightability indicated

sightability by day was not equal among all individual Key deer (P <0.001). Results of

model selection using Program MARK indicated no significant difference in sightability

by day between sexes (male = 0.244, SE = 0.031; female = 0.224, SE = 0.019).

Population estimates differed considerably between camera and FLIR survey

methods (Table 3.1). Camera-based surveys consistently produced higher abundance

estimates than FLIR counts. G-test results using camera derived estimates as expected

values indicated that the number of deer observed using FLIR methods was significantly

higher ($P = 0.012$) than population estimates derived from camera surveys using the

Peterson estimator.

Table 3.1. Comparison of abundance estimates using infrared-triggered cameras

and number of Key deer observed using aerial forward looking infrared-

thermography methods, Lower Florida Keys, Florida, USA.

Island complex	Total area surveyed (ha)	Deer observed using FLIR (2005)	Deer observed using FLIR (2006)	Camera-based estimate 2005-2006	MNKA[a]
Cudjoe	1,319	4	NS[b]	8	7
Howe	373	11	6	16	9
Knockemdown	582	NS[b]	5	9	3
Little Pine	382	4	7	12	4
Sugarloaf	1,399	7	6	25	12
Torch	1,341	NS[b]	3	38	10

[a] MNKA, absolute minimum number of individual Key known to be alive.
[b] NS, no survey was conducted.

DISCUSSION

    Because these surveys were conducted on sub-populations of unknown size, it is

not possible to compare accuracy between the 2 techniques. Camera-based surveys were

a more cost effective method to obtain estimates of Key deer abundance on outer islands.

The number of infrared-triggered cameras necessary for camera-based surveys varies

with island size and cost per camera unit varies among manufacturers. A minimum of 9

cameras was needed to survey the largest island (i.e., Sugarloaf). In this study, initial

investment for camera-based surveys was considerable-- approximately $330 per camera unit. However, once purchased the long-term cost of operation per survey was negligible-- approximately $5 per camera unit. Cost of the ThermaCAM® B-20 FLIR system was $28,000. Surveying all outer islands required approximately 8–10 hours of helicopter flight time, the cost of which would have varied from $350–600 per hour depending on type of helicopter used. Cost estimates do not include technician salaries.

Forward-looking infrared thermography technology is currently of limited use in Key deer management. I suggest that camera-based surveys, despite the amount of field work and time required, should be the preferred method to survey outer islands. Utility of FLIR-based surveys appears to be limited by low sightability due to dense tropical vegetation. Physiological characteristics such as small body size and behavioral characteristics such as secretive and solitary tendencies also may appreciably reduce sightability of Key deer using FLIR technology. Surveys based on FLIR technology are typically conducted under the assumption of complete or nearly perfect detection (e.g., Havens and Sharp 1998, Wiggers and Beckerman 1993, Dunn et al. 2002). Thus, FLIR-based surveys require that all Key deer be detected as this method represents a minimum count. However, results of camera-based surveys and failed observation of known Key deer numbers (50–57% of minimum known) indicate that only a small proportion of Key deer present on islands were detected using FLIR methods. It may be desirable to apply a correction factor for FLIR-based surveys of large mammals in tropical and sub-tropical environments or other areas exhibiting dense vegetation.

Sightability of Key deer using FLIR technology may have been limited by local

ambient temperatures. Havens and Sharp (1998) concluded that FLIR-based surveys

offered adequate sightability of large mammals at 25°C. Temperature during FLIR

surveys were within the limitations of the FLIR system. Thermal contrast also was

improved due to full or partial cloud cover during surveys. Key deer sighted using FLIR

were clearly visible, also indicating ambient temperature was not a limiting factor.

Although conducting FLIR surveys at night (Wiggers and Beckerman 1993, Garner et al.

1995, Graves et al. 1972) or pre-dawn (Havens and Sharp 1998) could provide improved

thermal contrast of large mammals, night flights were not possible during this study due

to flight restrictions. The utility of FLIR-based survey also may have been limited by

the capabilities of the camera equipment used in this study and other FLIR systems

might produce improved results. Further research is necessary to address sightability,

correction factors, and limitations of specific equipment in sub-tropical and tropical

environments.

CHAPTER VI

CONCLUSIONS AND IMPLICATIONS

The purpose of this chapter is to summarize current methods to survey Key deer on outer islands. This chapter provides a general summary of the research presented in this thesis. Additionally, this chapter provides management recommendations regarding estimating Key deer sub-population abundances on outer islands.

CAMERA-BASED SURVEYS

Camera-based surveys offer a practical and accurate method to monitor the spatial distribution on Key deer throughout their range. Results of this study indicate camera-based surveys may provide a practical method to estimate and monitor Key deer abundance and population trends on outer islands. In addition, camera-based surveys can provide a method to evaluate the efficacy of management actions on outer islands such as translocations and habitat manipulations. Similar sightability among male and female Key deer and use of natural marks minimized the temporal and financial costs associated with conducting surveys of abundance on outer islands. In addition, methods presented here alleviate the need to capture and mark individuals, thereby minimizing invasive and potentially harmful management actions.

Camera-based surveys should be conducted in August-September allowing maximal discrimination of antler configuration, assumption of mark retention, and minimization of behavioral bias due to rutting behaviors. Although baiting may not be necessary, it is acceptable to bait camera stations at initial camera station setup only if

the Peterson or Minta-Mangal estimators are used to estimate abundance. However, I

recommend that camera stations not be re-baited during surveys as this may introduce

further behavioral bias into population estimates. Surveys should be conducted for 20

consecutive days as this timeframe allows collection of sufficient data and capture of

most individual Key deer. I recommend the addition of multiple recapture sessions to

address inherent variability and address the accuracy of Key deer abundance estimates

for individual islands. Camera density should be a minimum of 1 camera per 50 ha of

Key deer habitat.

All methods used to develop abundance estimates presented in Chapter II are

subject to biases associated with small samples sizes and sightability of individual deer.

Sightability of individual Key deer is an inherent problem when estimating Key deer

abundance using camera-based methods. Methods developed by Minta and Mangel

(1989) address variability in individual sightability and I recommend the Minta-Mangal

estimator be used when estimating Key deer abundance on outer islands. Additionally, I

recommend further validation of camera-based survey methods for Key deer. Managers

should be cognizant of potential biases inherent in camera-based estimates of Key deer

abundance and derived estimates should be used with prudence in management of Key

deer. A single estimate of population size provides little information about the status of

a population (Lancia et al. 1996). Thus, I recommend camera-based surveys be

conducted annually to monitor population status and trends on outer islands. If annual

surveys are not feasible, I recommend the development of a rotational survey scheme

which focuses on primary sub-populations such as Cudjoe, Howe, Little Pine, and Sugarloaf.

FLIR-BASED SURVEYS

I tested the utility of forward looking infrared-thermography (FLIR) technology to estimate abundance of Key deer on outer islands using aerial survey methods. Utility of FLIR-based aerial surveys appears to be limited by low sightability due to dense tropical vegetation. Although no test of accuracy was possible, results indicate that FLIR-based aerial survey methods are unreliable for the survey of large mammals in tropical habitats. Thus, FLIR-technology is currently of limited use in Key deer management and camera-based surveys should be the preferred method to survey Key deer abundance on outer islands. Physiological characteristics such as small body size and behavioral characteristics such as secretive and solitary tendencies also may appreciably reduce sightability of Key deer using thermal imaging. Results of known Key deer locations and survey method comparisons indicate that FLIR drastically underestimates Key deer abundance on outer islands. It may be desirable to apply a correction factor for FLIR-based surveys of large mammals in tropical and sub-tropical environments or other areas exhibiting dense vegetation. Use of aerial FLIR-based methods should be avoided when attempting to estimate Key deer abundance on outer islands. If aerial FLIR-based methods are used, I strongly recommend the development and application of correction factors for this type of survey.

MANAGEMENT IMPLICATIONS

Reclassification of Key deer from endangered to threatened has recently been proposed as a result of increased Key deer densities at the core of their range (i.e., Big Pine and No Name keys; Lopez et al. 2004). Attempts to establish viable sub-populations (Parker 2006) address other recovery criteria (USFWS 1999). Other recovery criteria such as the evaluation of status and trends of Key deer on islands will also play a key role in the decision making process. Information from this study will be useful during evaluation of the proposed reclassification of Key deer. Data from this study also will facilitate appropriate management and conservation of the endangered Key deer metapopulation throughout their range.

Results of occupancy surveys using traditional and camera-based methods indicate that the distribution of Key deer has decreased slightly since the early 1970s. Absence of Key deer on previously occupied islands such as Big Johnson and Summerland keys may be an indication of population declines on outer islands. The effects of recent hurricanes and changes in freshwater quality are possible explanations for the observed constriction in distribution. However, metapopulations are dynamic and the absence of Key deer on specific outer islands may be the result of natural fluctuation in meta-population structure. Factors effecting the distribution and abundance of Key deer throughout their range (e.g., fresh water) warrant further investigation.

Relative abundance among islands raises questions as to the factors limiting Key deer abundance on outer islands. Abundance estimates for all islands were well below

respective carrying capacities calculated by Lopez (2001). Islands such as Sugarloaf and Cudjoe have sufficient habitat and would be expected to maintain higher Key deer densities than observed. Furthermore, the absence of Key deer on previously occupied islands such as Big Johnson and Summerland keys is indicative of sub-population declines in nearby source populations. Research using models by Harveson et al. (2006) concluded that distance from source populations and island size significantly affects Key deer abundance on outer islands, and the results of this study support these conclusions. Larger natural populations of Key deer typically occurred on islands closest to Big Pine Key.

I recommend further evaluation of camera-based and other contemporary survey methods to estimate abundance of Key deer on outer islands. Future research needs include investigation of the general ecology of Key deer inhabiting outer islands. Primary emphasis should be applied to survival, fecundity, and recruitment on outer islands as these would be expected to have significant impacts on small local sub-populations. Dispersal rates (i.e., immigration and emigration) among outer islands also are important to the persistence of Key deer sub-populations and warrant further investigation.

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