ASPECTS OF KEY LARGO WOODRAT ECOLOGY

A Thesis

by

ROBERT ALAN MCCLEERY

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 2003

Major Subject: Wildlife and Fisheries Sciences

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December 2003

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ABSTRACT

Aspects of Key Largo Woodrat Ecology.

(December 2003)

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Development on the island of Key Largo, Florida, has isolated the Key Largo woodrat (KLWR, *Neotoma floridana smalli*) on approximately 850 ha of remaining habitat. The KLWR was listed as a federally endangered species in 1984, yet there is still only a limited amount of knowledge about its ecology and population dynamics. The objective of this study was to produce reliable information on KLWR ecology to aid in its management and recovery. Specifically, the study examined (1) the trend and status of the KLWR population, (2) KLWR habitat and nesting preferences, (3) the potential of a fatal disease on KLWR, (4) the movements and ranges of the KLWR, and (5) the viability of the KLWR population. I trapped on 60 (1-ha) grids from March to September 2002 and 10 (1-ha) grids in October 2002 and January, April, and July 2003. Additionally I radio-collared 17 KLWRs and tracked them from March to November 2002. I estimated the current population of KLWR to be between 26 and 106 individuals. I found KLWR selected young hammock (disturbed > 1971) over medium (disturbed between 1940-1971) and old hammock (disturbed < 1940). KLWRs selected garbage and rock piles in the young hammock for nesting sites. From the analysis of 64 raccoon (*Procyon lotor*) fecal samples, I have no evidence that the potentially fatal raccoon roundworm parasite (*Baylisascaris procyonis*) was present on Key Largo or had negative impact on the KLWR. Telemetry data indicated males have larger ranges than females. Females appear socially tolerant of one another and have significantly smaller ranges than males during the spring and summer breeding season. Results of a population viability analysis (PVA) using demographic parameters from previous studies and my study projected a high risk of extinction for the KLWR within the next 10 years. I recommend the creation of large continuous blocks of young (disturbed > 1971) habitat and the creation of nesting habitat for the KLWR within these areas. I would also advocate a large-scale captive breeding and augmentation of the population along with continued research on the limiting factors that are driving the KLWR toward extinction.

DEDICATION

Mom and Dad

Thank you for your love, strength, and selflessness

ACKNOWLEDGMENTS

Steve Klett and Phil Frank you made the woodrat and this project a priority. Credit for any progress or difference we made belongs to both of you. Thank you both for your encouragement, trust, and advice. Thank you to my technicians Kate Banick, Austin Crider, Eddie Lyons, and Erin Knoll for your sweat and hard work. I am grateful to Garry Foster and Donald Forrester for their lab work, suggestions, and edits. Also, I would like to thank Kathleen LoGiudice and Steve Castleberry for their time and valuable advice on working with woodrats. To my committee Roel Lopez, Nova Silvy, and Donald Davis thank you for your council and guidance during my time at Texas A&M University and in Key Largo. Roel Lopez and Nova Silvy, thank you for finding the time, energy, and patience to listen and provide insight for my project and life. I also thank Texas A&M University, the Texas Agricultural Experiment Station, and the U.S. Fish and Wildlife Service (Crocodile Lake National Wildlife Refuge and Ecological Services – Vero Beach) for financial assistance. Mom and Dad thank you for your unobtrusive, all pervasive, endless supply of love.

TABLE OF CONTENTS

Page

ABSTRACT iii

DEDICATION v

ACKNOWLEDGMENTS vi

TABLE OF CONTENTS vii

LIST OF FIGURES ix

LIST OF TABLES x

CHAPTER

I INTRODUCTION 1

- Background 1
- Study Area 3
- Objectives 3

II POPULATION TRENDS AND STATUS 5

- Synopsis 5
- Introduction 6
- Methods 7
- Results 9
- Discussion 14
- Management Implications 16

III HABITAT PREFERENCES AND NEST SELECTION 18

- Synopsis 18
- Introduction 19
- Methods 21
- Results 24
- Discussion 30
- Management Implications 31

TABLE OF CONTENTS (Continued)

CHAPTER Page

IV RACCOON ROUNDWORM: A FACTOR IN THE DECLINE OF THE KEY LARGO WOODRAT? 33
Synopsis 33
Introduction 34
Methods 35
Results 37
Discussion 37

V RANGES AND MOVEMENTS OF THE KEY LARGO WOODRAT 39
Synopsis 39
Introduction 40
Methods 43
Results 46
Discussion 47

VI VIABILITY OF THE KEY LARGO WOODRAT 49

Synopsis 49
Introduction 50
Methods 51
Results 55
Discussion 61

VII CONCLUSIONS 63

LITERATURE CITED 65

VITA 73

LIST OF FIGURES

FIGURE		Page
1.1	The island of Key Largo, Florida, and KLWR study site comprised of the known KLWR range..….....................................	4
2.1	Comparison of 3 population indices (stick-nest density, population density estimates, and trap success) for the KLWR, Key Largo, Florida, 1976-2002…..………………………………	12
2.2	KLWR population estimates and 95% CI from March 2002–July 2003, Key Largo, Florida……………………………………. …...	13
3.1	Vegetation classification of KLWR habitat by age-class (young, medium, old) on Key Largo, Florida, 2002..…………...................	22
3.2	Frequency of KLWR nest-site selection by nest substrate and sex, Key Largo, Florida, 2002………………………………………….	29
3.3	Frequency of KLWR nest-site selection by hammock age-class and sex, Key Largo, Florida, 2002………………………………..	29
5.1	The northern third of the island of Key Largo, Florida, KLWR habitat and County Road 905……………………………………..	42
6.1	Population trajectories for simulations of the KLWR population with varying numbers of introductions (0 female [S0], 5 female [S5], 10 female [S10], and 20 female [S20]) using low, medium, and high parameter estimates, Key Largo, Florida, 2002-2012…..	57
6.2	Sensitivity analysis (difference in risk extinction between high and low parameter values) of model results to 6 parameters for the KLWR population, Key Largo, Florida, 2002………………...	59
6.3	Simulated population trajectories for the KLWR population using low, medium, and high parameter estimates from 1996–2006. Note, 2002 KLWR population estimates………………………….	60

LIST OF TABLES

TABLE Page

2.1 Naïve density estimates for KLWR by study, year, number of grids, and age-class of forest trapped, Key Largo, Florida……… 11

3.1 Summary of vegetative characteristics for KLWR habitat by age-class (young, medium, old), Key Largo, Florida, 2002…….. 26

3.2 Summary of vegetative characteristics for KLWR habitat in young hammock on 1-ha grids with and without KLWR captures, Key Largo, Florida, 2002…………………………… 27

3.3 Pair-wise and nonparametric comparisons of vegetative characteristics found to be significant for KLWR habitat by age-class (young, medium, old)……………………………………… 28

5.1 Average MCP monthly and seasonal KLWR range sizes by sex, Key Largo, Florida.. 45

5.2 Differences in monthly and seasonal MCP KLWR ranges by sex and season, Key Largo Florida………………………………….. 45

6.1 Low, medium, and high parameter estimates used in population viability analysis for KLWR population………………………… 56

6.2 Summary of terminal extinction risks (mean 95% ± CI) for population by management scenarios using low, medium and high parameter estimates, Key Largo, Florida, 2002-2012........... 58

CHAPTER I

INTRODUCTION

BACKGROUND

The endangered Key Largo woodrat (KLWR, *Neotoma floridana smalli*) is in desperate need of research and management action to prevent its further decline and possible extinction. This sub-species of the eastern woodrat (*N. floridana*) is endemic to the island of Key Largo and isolated from the nearest sub-species by at least 210 km (Greer 1978).

In 1984, the KLWR was classified as a federally endangered species because of concerns over habitat loss and the impact of commercial development (U. S. Department of Interior [DOI] 1984). Forty-seven percent of the KLWR's tropical hardwood hammock habitat has been lost (Strong and Bancroft 1994), and since 1973 the KLWR has been confined to approximately 850 ha of remaining forest on the northern third of Key Largo (DOI 1973, Barbour and Humphrey 1982). Most of these 850 ha are within the bounds of 2 protected areas: the Dagny Johnson Key Largo Hammock Botanical State Park and the Crocodile Lake National Wildlife Refuge (Frank et al. 1997).

Research suggests the KLWR prefers mature or climax hammock habitat (DOI 1973, Brown 1978, Hersh 1978, Barbour and Humphrey 1982, Goodyear 1985, U. S. Fish and Wildlife Service [USFWS] 1999). These conclusions stemmed from observations of high densities of woodrat stick-nests within mature hammock (Brown

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The format and style follow the *Journal of Wildlife Management*.

1978, Hersh 1978, Barbour and Humphrey 1982). Other studies have reported the KLWR will use hammock forests in varying degrees of succession (Goodyear 1985, Keith and Gaines 2002, Sasso and Gaines 2002). Reliable knowledge regarding the habitat preferences for the KLWR is lacking, and critical to the management and recovery of this species.

For the last 2 decades, research has suggested the KLWR population has declined even within protected areas (Frank et al. 1997, USFWS 1999). Still, little is known about KLWR ecology and what may be causing its decline. Feral cats (*Felix domestica*, Humphrey 1992, Frank et al. 1997, USFWS 1999), fire ants (*Solenopsus spp.*, Frank et al. 1997), habitat fragmentation (Goodyear 1985, Frank et al. 1997, USFWS 1999), competition with black rats (*Rattus rattus*, Hersh 1981, Humphrey 1992, Frank et al. 1997, USFWS 1999), and a combination of the above (Frank et al. 1997) have been suggested, but there is little or no data to support these hypotheses. Another possible explanation is raccoon roundworm (*Baylisascaris procyonis*) which has been shown to have negative effects on the survival of the Alleghany woodrat (*N. magister*, McGowan 1993, LoGiudice 2001, LoGiudice 2003).

In 2003, USFWS biologists were concerned about the collapse of the KLWR population and began efforts for a captive breeding program of the KLWR. One of the primary goals of the program was to release captive-reared KLWRs into suitable native habitat (Dean 2003).

STUDY AREA

Key Largo is the first and largest in a chain of islands (keys) that extends off the southern tip of Florida. My study area on Key Largo was limited to KLWR habitat (845 ha) found along an 11-km stretch of protected hardwood hammock forest on the northern third of the island (Fig. 1.1). The hardwood hammock habitat on the island of Key Largo is unique, with a high abundance of West Indian plants and trees (Strong and Bancroft 1994, USFWS 1999). Some common trees found in Key Largo's hammocks are gumbo-limbo (*Buresa simaruba*), poisonwood (*Metopium toxiferum*), wild tamarind (*Lysiloma bahamensis*), pigeon plum (*Cocoloba diversifolia*), willow bustic (*Bumelia salicifolia*), and Jamaican dogwood (*Piscidia fostidissimum*).

OBJECTIVES

The objectives of my study were to:

1. Examine trends and current status of the KLWR population.
2. Determine KLWR habitat and nesting preferences.
3. Determine the impact of raccoon roundworm on the KLWR.
4. Examine movements and ranges of the KLWR.
5. Assess the risk of extinction and the potential for augmentation of the KLWR population.

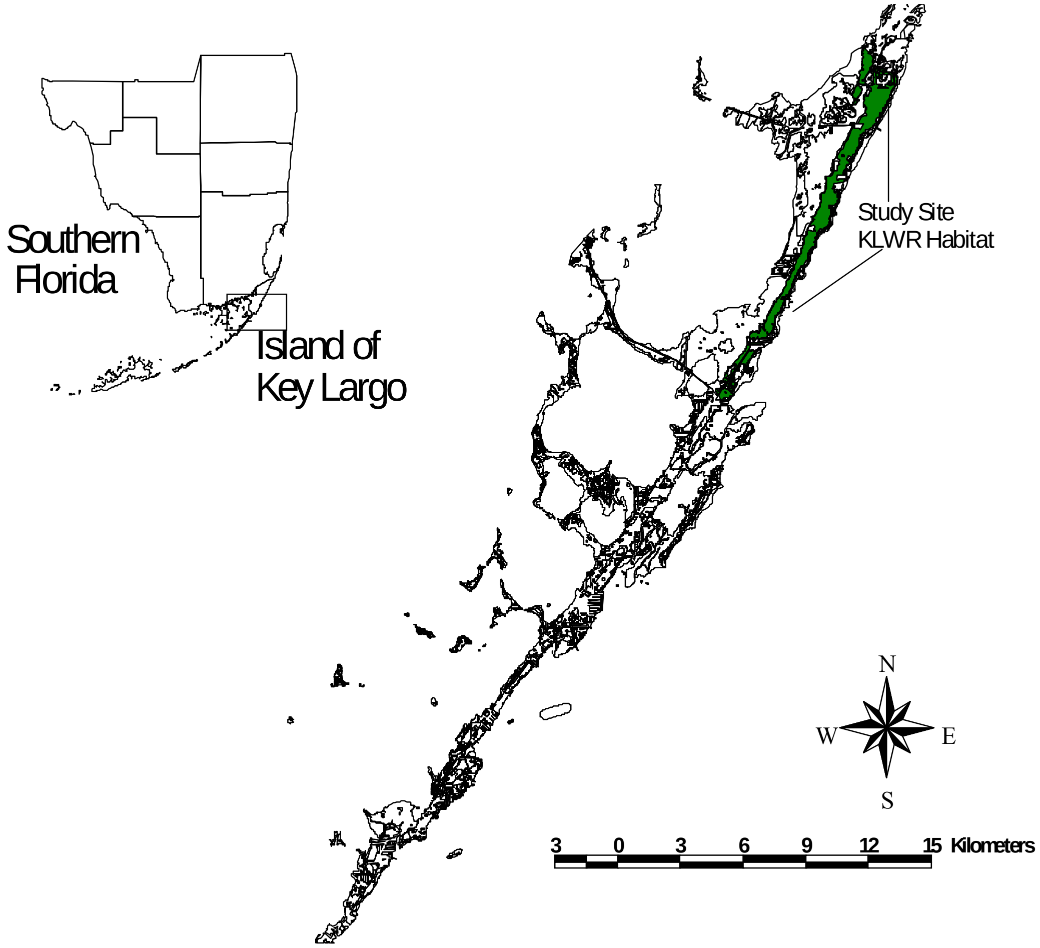

Fig 1.1. The island of Key Largo, Florida, and KLWR study site comprised of the known KLWR range.

CHAPTER II

POPULATION TRENDS AND STATUS

SYNOPSIS

Development and forest clearing isolated the endangered Key Largo woodrat (KLWR, *Neotoma floridana smalli*) into approximately 850 ha of remaining hardwood hammock forest on the northern third of the island of Key Largo, Florida. Research has suggested the KLWR population has declined in the last 2 decades; however, population trends have not been examined, and current population estimates are lacking. I examined trends in the KLWR population from available published and unpublished data of KLWR stick-nest density, trap success, and population density estimates. I calculated current population estimates were calculated from trapping on 60 (1-ha) randomly-placed (20 grids in 3 age-classes) trapping grids between March-September 2002. Additional population estimates (October 2002, January 2003, April 2003, and July 2003) by re-trapping grids (of the 60) with initial KLWR captures. Data indicates that stick-nest density, trap success, and KLWR population density estimates have all declined over the last 25 years. Current population estimates for the KLWR population were: 106 (95% CI = 30-182) between March-September 2002, 26 (95% CI = 8-40) during October 2002, 46 (95% CI = 7 -105) during January 2003, 30 (95% CI = 6-56) during April 2003, and 38 (95% CI = 5-98) during July 2003. The decline of stick-nest density, trap success, and population density estimates of the KLWR provides compelling evidence the KLWR has been declining for the last 25 years. Population

estimates also suggest that the KLWR population is critically low and at great risk of extinction.

INTRODUCTION

The manatee (*Trichechus manatus*), Florida panther (*Puma concolor coryi*), and Key deer (*Odocoileus virginianus clavium*) are highly visible endangered species in South Florida. Yet the most critically endangered of all mammals in the region is the little-known Key Largo woodrat (KLWR), which could be lost to extinction. The KLWR is endemic to the island of Key Largo and isolated from the Florida woodrat (*N.f. floridana*) by at least 210 km (Greer 1978). In 1984, the KLWR was classified as a federally endangered species because of concerns over habitat loss and the impact of commercial development (U. S. Department of Interior [DOI] 1984). Forty-seven percent of the KLWR's tropical hardwood hammock habitat has been lost (Strong and Bancroft 1994) and since 1973, the KLWR has been confined to approximately 850 ha of remaining forest on the northern third of Key Largo (DOI 1973, Barbour and Humphrey 1982). Most of these 850 ha are within the bounds of 2 protected areas: Dagny Johnson Key Largo Hammock Botanical State Park and Crocodile Lake National Wildlife Refuge (Frank et al. 1997). For the last 2 decades, research has suggested the KLWR population has declined even within these protected areas (Frank et al. 1997, U.S. Fish and Wildlife Service [USFWS] 1999). However, current population estimates necessary for the KLWR's management and recovery are lacking.

Eastern woodrats are known for their ability to build stick-nests or houses for shelter and food storage (Rainey 1956, Wilson and Rue 1999). The KLWR is no exception; it has long been characterized by large and prolific stick-nest building (Small 1923, Schwartz 1952, Brown 1978). The recent disappearance of these structures on north Key Largo has generated concern over the status of the KLWR population. It is the purpose of this chapter is to: (1) review KLWR population trends from available data and (2) estimate the current population size of the KLWR population.

METHODS

Study Area

Key Largo is the first and largest in a chain of islands (keys) that extends from the southern tip of Florida. My study area on Key Largo was limited to KLWR habitat (845 ha) found along an 11-km stretch of protected hardwood hammock forest on the northern third of the island (Fig. 1.1). The hardwood hammock habitat on the island of Key Largo is unique, with a high abundance of West Indian plants and trees (Strong and Bancroft 1994, USFWS 1999). Some common trees found in Key Largo's hammocks are gumbo-limbo (*Buresa simaruba*), poisonwood (*Metopium toxiferum*), wild tamarind (*Lysiloma bahamensis*), pigeon plum (*Cocoloba diversifolia*), willow bustic (*Bumelia salicifolia*), and Jamaican dogwood (*Piscidia fostidissimum*).

Population Trends

I evaluated 3 population indices of the KLWR population from data collected between 1923–2001. Three indicators were used because single indicators may be of limited value (Lancia et al. 1996).

Stick-Nest Density.—Available KLWR stick-nest data were collected from a review of published and unpublished data sources (Hersh 1981, Barbour and Humphrey

1982, Frank et al. 1997, USFWS 2001, unpublished data). Data sources, year, stick-nest density (stick-nests/ha) estimates, and pertinent comments were recorded. I observed stick-nest density within 60 randomly-placed trapping grids (1 ha) created between March-September 2002.

Population Density.—Density estimates (KLWR/ha) were collected from a review of published and unpublished data sources (Hersh 1981, Barbour and Humphrey 1982, Humphrey 1988, Frank et al. 1997, USFWS 2001, unpublished data). I recorded data sources, year of fieldwork, reported age of hammocks trapped, number of grids trapped, and calculated KLWR population density estimates. KLWR densities (KLWR/ha) were standardized using naïve density estimates (Krebs 1999).

Trap Success.—Trap success data (traps containing a KLWR/number of trap nights) were collected from a review of published and unpublished data sources (Hersh 1981, Goodyear 1985, Humphrey 1988, Frank et al. 1997, USFWS 2001, unpublished data). Trap success was compared to other survey index data.

Current Population Density

I divided the vegetation types of the study area into 3 classes based on age: young hammock (disturbed > 1971; 87 ha), medium hammock (disturbed between 1940–1971; 327 ha), and old hammock (disturbed < 1940; 431 ha). Hammock types were generated in ArcView Version 3.1 using aerial photos and previous vegetation studies (Ross et al. 1995). Twenty random points were generated within each age-class using a random point generator (Jenness 2001). At each random point, a 1-ha trapping grid was placed. Each grid consisted of 25 (5 rows x 5 columns) traps (vented Sherman traps with raccoon (*Procyonis lotor*) proof latches Model PXLF15) placed 25-m apart. Between March–September 2002, traps were baited with crimped oats and peanut butter wrapped in paper, and opened for 4 consecutive nights. Captured KLWRs were marked with an ear tag, and their sex, age, weight, and capture history were recorded. I separated KLWRs into 2 age-classes (adult and juvenile) based on their weight and pelage (Frank et al. 1997). Grids with KLWR captures were re-trapped for trend data in October 2002, January 2003, April 2003, and July 2003. Naïve population estimates (Krebs 1999) and 95% confidence intervals (CI) were generated for each age-class during each trapping period. KLWR densities (KLWR/ha) were calculated for each cover type by multiplying the total area (ha) of each age-class by the estimated KLWR densities. Ninety-five percent CI were adjusted to ensure low estimates were not less than the number of individual KLWR captured during a trapping period.

RESULTS

Population Trends

Stick-Nests.—The first mention of KLWR stick-nests was by Small (1923:215), when he noted that rats build “a shack 2 to 3 feet wide and 4 to 6 feet long.” Schwartz (1952) reported stick-nests to be a conspicuous feature of the Key Largo hammock. From Hersh’s (1981) work in 1976 and 1977, I calculated a stick-nest density estimate of 12 stick-nests/ha (Fig. 2.1). Barbour and Humphrey (1982) estimated 7.7 stick-nests/ha from fieldwork in 1979. In 1986, Humphrey noted there were fewer stick-nests than in 1979, and they were smaller and not as well kept as he had previously observed (S. R. Humphrey, University of Florida, personal communication). Trapping on 4 (2.7

ha) grids and 41 transects in 1995 Frank et al. (1997), only recorded 1 stick-nest. Similarly, during trapping on 4 (1.8 ha) grids and 25 transects in 2000 and 2001, only 1 stick-nest was observed (USFWS 2001, unpublished data). In 2002, I did not observed a single stick-nest on my study area.

Population Density.—From 1976–2001, most KLWR density estimates were generated from trapping in old and medium aged hammock (Table 2.1). KLWR populations were between 2-3 KLWR/ha in the late 1970s, dropped to 1 KLWR/ha by 1996, and were 0.6 KLWR/ha by 2001 (Fig. 2.1). Humphrey (1988) noted an unusually high density estimate of 7 KLWR/ha in 1986.

Trap Success. —Trap success of KLWR has steadily declined since 1976 when intensive trapping efforts of KLWRs began (Fig. 2.1). In 1976, it took an average of approximately 15 trap nights to capture a KLWR compared to 250 trap nights in 2001.

Current Population Density

Sixteen KLWR captures of 13 individuals were recorded between March-September 2002 during trapping on all 60 grids. KLWRs were captured on 10 of 60 grids, 8 in young hammock, 2 in medium aged hammock, and 0 in old hammock. The KLWR population was estimated at 106 (95% CI 30-182) individuals. Trend data trapping (10 grids) yielded population estimates of 26 (95% CI = 8-40, October 2002), 46 (95% CI = 7-105, January 2003), 30 (95% CI = 6 – 56, April 2003), and 38 (95% CI = 5-98 July) KLWRs (Fig. 2.2).

Table 2.1. Naïve density estimates for KLWR by study, year, number of grids, and age-class of forest trapped, Key Largo, Florida.

Researcher	Year	Number of grids	Age-class	Density
Hersh 1981	1976	1 grid	old	2.2/ha
Barbour and Humphrey 1982	1979	2 grids	old/medium	2.8/ha
Humphrey 1988	1986	6 grids	old/ medium/ young	7/ha
Frank et al. 1997	1995-6	4 grids	old/medium	1/ha
UFWS 2001	2000-1	4 grids	old/medium	.6/ha

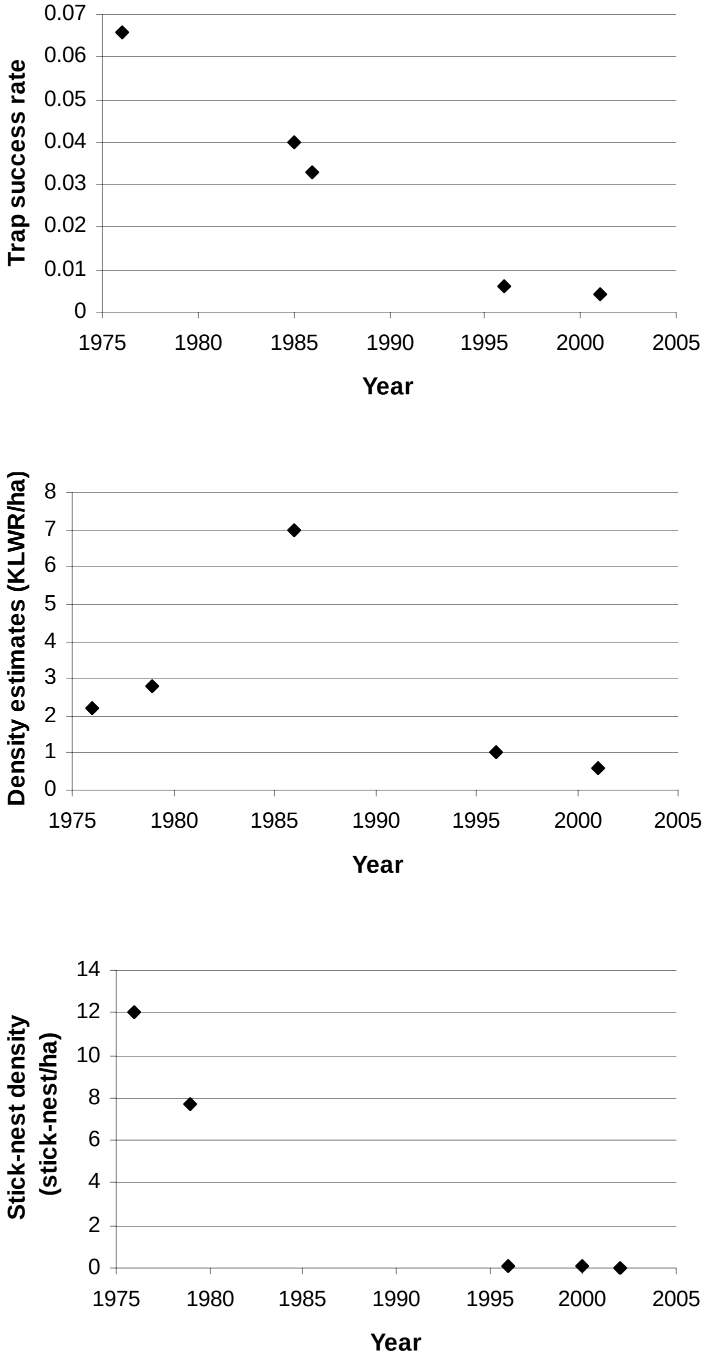

Fig. 2.1. Comparison of 3 population indices (stick-nest density, population density estimates, and trap success) for the KLWR, Key Largo, Florida, 1976–2002.

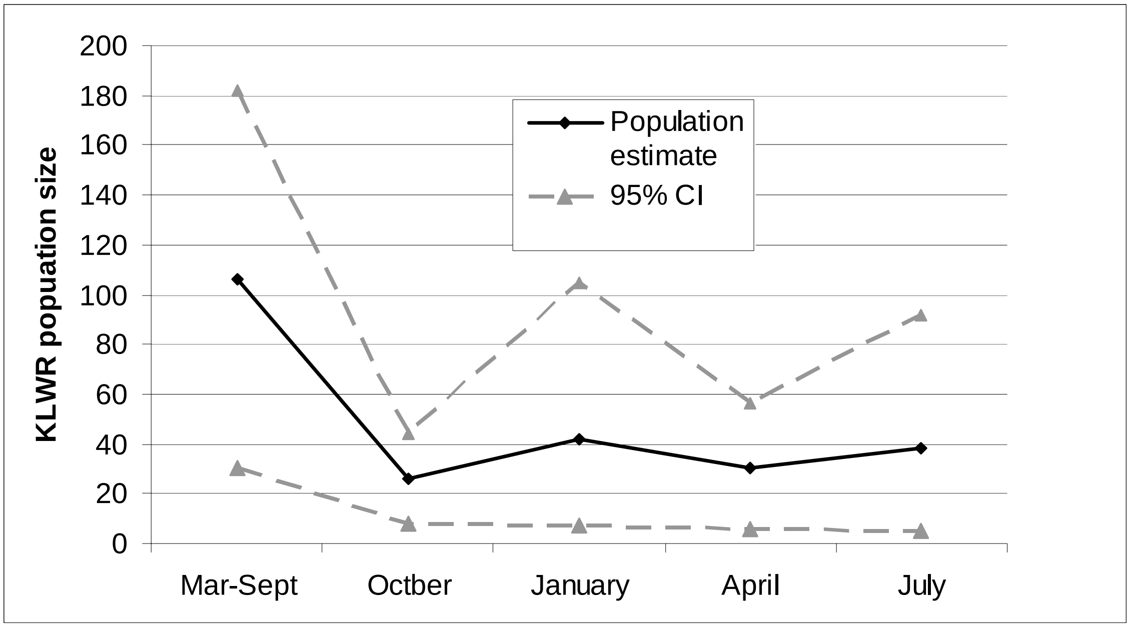

Fig. 2.2. KLWR population estimates and 95% CI from March 2002–July 2003, Key Largo, Florida.

DISCUSSION

Population Trends

Stick-Nests.—The KLWR population appears to be only loosely correlated with woodrat stick-nest abundances (Goodyear 1985, Humphrey 1988) because of the KLWR's ability to use other areas for nesting. The disappearance of stick-nests on north Key Largo however, does suggest a decline in the KLWR population. Loss and deterioration of stick-nests has been connected with localized decreases and extinctions of other woodrat populations (Fitch and Rainey 1956, Smith et al. 1993). Additionally, a dramatic decline in the number of stick-nest was associated with an extinction of an introduced population of the KLWRs on Lignumvitae Key, Florida (J. G. Duquesnel, Florida Department of Environmental Protection, unpublished data).

Population Density.—The population density estimate of 7 KLWR/ha (Humphrey 1988) was incongruous with other estimates. That estimate was more than double any previous KLWR estimate and the highest density ever recorded for any eastern woodrat population (Fitch and Rainey 1956, Rainey 1956, Goetz 1970, Wilson 1999, HaySmith 1995). Eastern woodrat density estimates have been consistently between 2-3 woodrats/ha. If Humphrey's (1988) estimate was accurate, the decline of the KLWR population to densities of 1 and 0.6/ha (Frank et al. 1997, USFWS 2001, unpublished data) becomes even more alarming. However, it would be misleading to compare each of the 5 studies (Table 2.1) without making note of their differences and shortcomings. The areas trapped were of differing sizes, trap arrangements, and distances between traps. Additionally, small sampling area (< 20 ha) and biases in selection of trapping areas (e.g. vegetation types different) in all the studies hindered estimates. For these reasons, density estimates presented here should be viewed with caution.

Trap Success. —Trap success data indicated an increase in the effort needed to capture a KLWR, suggesting a population decline. This simple way of measuring KLWR abundance was vital because of the lack of continuity and standardization of trapping methodology of previous studies. However, trap density also can influence these estimates.

Declines in stick-nest density, population density estimates, and trap success all during a similar time frame provides compelling evidence the KLWR has been declining over the last 25 years. It has been suggested that the KLWR population has simply been experiencing normal population cycles (Frank et al. 1997, S. R. Humphrey, University of Florida, personal communication), yet a review of woodrat research does not support this premise. Woodrats have been shown to fluctuate (especially with severe weather) by month, season, and year on specific grids or trapping areas (Fitch and Rainey 1956, Goetz 1970, HaySmith 1995). Yet I found no records of densities as low as those observed for the KLWR, or with decreases of the same magnitude from which a woodrat population rebounded.

Current Population Density

The March-September 2002 estimate of 106 KLWRs highlights the KLWR's decline to precariously low numbers, especially since this estimate was likely high for several reasons. First, density estimates from trapping grids are generally inflated because animals caught on grid edges likely have ranges outside the grid (Krebs 1999). From a concurrent radio-telemetry data, this appears to be true. Second, over 80% of the KLWRs captured were in young hammock, which is comprised of small patches of habitat accounting for only 10.3% (87 ha) of the available hammock. Additional trapping efforts in these areas, used to complement the project, yielded only an additional 3 KLWRs. Projecting an equal density of KLWRs on the 67 un-trapped ha of young hammock also may have inflated population estimates. Later population estimates of 26, 42, and 30 also suggest the original estimate of 106 was likely an overestimation of the population.

MANAGEMENT IMPLICATIONS

No clear evidence has been found to explain the decline of the KLWR. Feral cats (*Felix domestica*, Humphrey 1992, Frank et al. 1997, USFWS 1999), fire ants (*Solenopsus spp*., Frank et al. 1997), habitat fragmentation (Goodyear 1985, Frank et al. 1997, USFWS 1999), competition with black rats (*Rattus rattus*) (Hersh 1981, Humphrey 1992, Frank et al. 1997, USFWS 1999), disease (USFWS 1999), and a combination of factors have all been suggested (Frank et al. 1997); but there is little or no data to support any of these hypotheses. My study suggests that competition with black rats is likely not a major concern. Black rat densities were once found at levels similar to the KLWR (Hersh 1981, Frank et al. 1997). After 10,000 trap nights, however, I recorded only 16 black rat captures. Future research is necessary to determine the cause the KLWR's population decline. Results from my study suggest the KLWR population is critically low. The KLWR fits 3 of 5 criteria put forth by the

World Conservation Union (IUCN) for classification of critically endangered species (Hilton-Taylor 2000). Currently, money, management, man-power, research, and education are focused on Florida's other more charismatic mega-fauna like the Key deer, manatee, and Florida panther. Similar efforts should be made for the KLWR to determine and eliminate the causes of decline. Otherwise, the KLWR's extinction seems inevitable.

CHAPTER III

HABITAT PREFERENCES AND NEST SELECTION

SYNOPSIS

The endangered Key Largo woodrat (KLWR, *Neotoma floridana smalli*) population is at critically low levels. Effective management and recovery of this species requires basic ecological information, but reliable knowledge of KLWR habitat preferences and nest-site selection are lacking. KLWRs were trapped between March–September 2002 on 60 randomly placed 1-ha grids (25 traps) to determine habitat preferences. Twenty grids were placed into 1 of 3 hammock age-classes: young (disturbed > 1971, 87 ha), medium (disturbed between 1940–1971, 327 ha), and old (disturbed < 1940, 431 ha). Vegetation characteristics were measured within each grid and at traps recording a KLWR capture: (1) percent canopy closure, (2) overstory tree density, (3) overstory tree size, (4) stem density, (5) understory tree density, and (6) fallen log density, (7) overstory tree species composition. Additionally, 17 KLWRs (7 males, 10 females) were collared and tracked twice weekly during daylight hours to determine nest-site selection. I recorded 13 KLWRs in young hammock on 8 grids, 3 KLWRs in medium hammock on 2 grids, and 0 KLWRs in old hammock. Variation of vegetative characteristic among age-classes was greatest for young hammock, while old and medium aged hammocks were more similar in their vegetative characteristics. In general, KLWRs selected grids in young hammock with an opened canopy and fewer

Jamaican dogwood trees (*Piscidia fostidissimum*). KLWR preference for open canopy appears to be highly correlated with the thick tangle of under-growth that characterized these areas. Radio-collared KLWRs preferred rock piles and garbage piles for nest-sites over other nesting areas. Additionally, they selected young hammock (83%) for their nest-sites. Study results suggest young hammock habitat is preferred by the KLWR, and I recommend the creation of large patches (> 20 ha) of young forest through burning, clearing, or other restoration practices.

INTRODUCTION

The endangered Key Largo woodrat (KLWR) is endemic to the island of Key Largo, Florida. In 1984, it was classified as a federally endangered species because of concerns over habitat loss and the impact of commercial development (U. S. Department of Interior [DOI] 1984). Forty-seven percent of the KLWR's tropical hardwood hammock habitat has been lost from the island and most of what remains has been cleared, thinned, developed, and fragmented (Strong and Bancroft 1994). Since 1973, the KLWR has been confined to approximately 850 ha of remaining forest on the northern third of Key Largo (DOI 1973, Barbour and Humphrey 1982). Most of these 850 ha are within the bounds of 2 protected areas: the Dagny Johnson Key Largo Hammock Botanical State Park and the Crocodile Lake National Wildlife Refuge (Frank et al. 1997). Even within these protected areas the KLWR has suffered from at least 2 decades of decline (Chapter II). Population trend data from trapping suggests a precipitous decline in the population with current estimates between 26-106 individuals (Chapter II).

Research on the KLWR suggests the species prefers mature or climax hammock habitat (DOI 1973, Brown 1978, Hersh 1978, Barbour and Humphrey 1982, Goodyear 1985, U. S. Fish and Wildlife Service [USFWS] 1999). These conclusions stemmed from observations of high densities of woodrat stick-nests within mature hammock (Brown 1978, Hersh 1978, Barbour and Humphrey 1982). In some cases, it was reported that the KLWR avoids young and intermediate aged hammocks (DOI 1973, Brown 1978). Other studies have reported the KLWR will use hammocks of varying degrees of succession (Goodyear 1985, Keith and Gaines 2002, Sasso and Gaines 2002). Reliable knowledge regarding the habitat preferences of KLWR is lacking, and important to the management and recovery of this species.

Eastern woodrats (*N. floridana*) are known for their ability to build stick-nests or houses for shelter and food storage (Rainey 1956, Wilson and Rue 1999). The KLWR is no exception; it has long been characterized by large and prolific stick-nest building (Small 1923, Schwatz 1952, Brown 1978). However, the disappearance of stick-nests on Key Largo over the last 20 years has been well documented (Chapter II). Previous research suggested KLWRs only occupied areas with stick-nests (Brown 1978, Hersh 1981, Barbour and Humphrey 1982). It was later noted that KLWRs did not exclusively use stick-nests for shelter. They were observed using rock piles, burrows, fallen trees, and even piles of trash for nesting sites (Goodyear 1985, Humphrey 1992). Short of these observations, no research efforts have been undertaken to determine KLWR's nest-site selection now that that their once prolific stick-nests are no longer evident. It is the purpose of this chapter to: (1) examine KLWR habitat preference at 2 scales and (2) to determine KLWR nest-site selection.

METHODS

Study Area

Key Largo is the first and largest in a chain of islands (keys) that extends from the southern tip of Florida. My study area on Key Largo was limited to KLWR habitat (845 ha) found along an 11-km stretch of protected hardwood hammock forest on the northern third of the island (Fig.1.1). The hardwood hammock habitat on the island of Key Largo is unique, with a high abundance of West Indian plants and trees (Strong and Bancroft 1994, USFWS 1999). Some common trees found in Key Largo's hammocks are gumbo-limbo (*Buresa simaruba*), poisonwood (*Metopium toxiferum*), wild tamarind (*Lysiloma bahamensis*), pigeon plum (*Cocoloba diversifolia*), willow bustic (*Bumelia salicifolia*), and Jamaican dogwood (*Piscidia fostidissimum*).

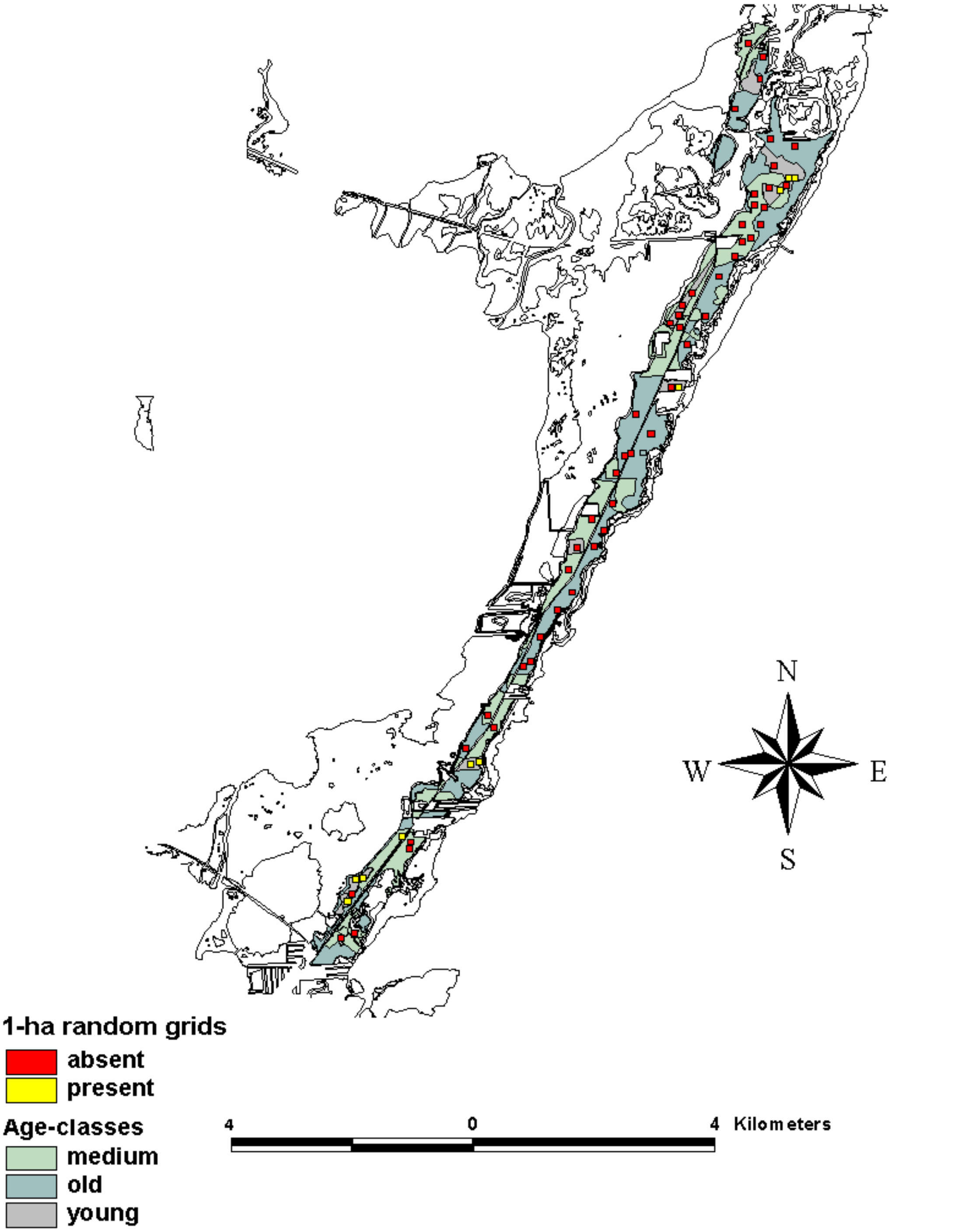

Fig 3.1. Vegetation classification of KLWR habitat by age-class (young, medium, old) on Key Largo, Florida, 2002.

Habitat Preferences

I divided the study area into 3 age-classes: young hammock (disturbed > 1971; 87 ha), medium hammock (disturbed between 1940–1971; 327 ha), and old hammock (disturbed < 1940; 431 ha). Age classes were generated in ArcVeiw (Version 3.1) using aerial photos and previous vegetation studies (Ross et al. 1995). Twenty random points were generated within each age-class using a random-point generator (Jenness 2001). At each random point, a 1-ha trapping grid was placed (Fig. 3.1). Each grid consisted of 25 (5 rows X 5 columns) traps (vented Sherman traps with raccoon [*Procyonis lotor*] proof latches Model PXLF15) placed 25-m apart. Between March–September 2002, grids were sampled (approximately 2 grids/week); traps were baited with crimped oats and peanut butter wrapped in paper and opened for 4 consecutive nights.

To quantify differences in vegetative characteristics between grids, measurements were taken on every third trap (1, 4, 7, 10, 13, 16, 19, 22,and 25) of every grid and on every trap recording a KLWR capture. The following vegetation characteristics were recorded within a 10-m plot centered at the trap as described by Dueser and Shugart (1978): (1) percent canopy closure (canopy), (2) overstory tree density (ost), (3) overstory tree size (dbh), (4) stem density (std), (5) understory tree density (ust), (6) fallen log density (logs) and (7) overstory tree species composition. The species of the overstory tree closest to the trap in each quadrant of the plot was recorded.

To incorporate the sensitivity of small mammals to habitat factors on different spatial scales, I chose to evaluate the relationship of vegetative characteristics to the

KLWR on 2 scales. First, I evaluated the differences in KLWR captures between hammock age-classes and then examined the difference in vegetative characteristics between age-classes. Second, I examined the differences in vegetative characteristics and tree composition between grids of the same hammock age-class with and without KLWR captures. I analyzed normally distributed data with bi-linear logistic regression, general linear models, and pair-wise comparisons. Pair-wise comparisons were made using Tukey's W procedure ($P < 0.05$) (Ott 1993). Non-normal data were evaluated using a Kurskal-Wallis test ($P < 0.05$) (Ott 1993). If non-normal data proved to be significantly different, additional Kurskal-Wallis tests were used to determine differences between individual variables. Statistical analyses were performed using MINITAB statistical software at the $P = 0.05$ level.

Nest-site Selection

Trapped KLWRs were radio-tagged with 7-g radio collars (AVM Instrument Company, Colfax, California) with mortality sensors (Model G3). KLWRs were located twice weekly via homing (Samuel and Fuller 1996) during daylight hours to locate their nest-sites. Nest substrate (rocks/rock piles, garbage, roots of fallen tree, roots of standing trees, logs or stump), date, cover type, and UTM coordinates were recorded at each nest-site.

RESULTS

Habitat Preferences

Ten of the 60 randomly-placed grids (Fig 3.1) recorded 16 KLWRs. I recorded 13 KLWRs in young hammock on 8 grids, 3 KLWRs in medium hammock on 2 grids, and 0 KLWRs in old hammock. All of the vegetative characteristics examined were significantly different between hammock age classes (Table 3.1). Pair-wise comparisons showed young hammock was characterized by: smaller overstory trees, fewer logs, a lower density of overstory trees, fewer pigeon plums, greater wild tamarinds, and a greater open canopy. Additionally, young hammock had a greater stem density than old hammock, and a lower density of understory trees than medium-aged hammock (Tables 3.1 and 3.3). The difference between medium aged and old hammock was less varied, differing only in tree size, canopy cover, and the abundance of wild tamarinds (Tables 3.1 and 3.3).

Differences in vegetative characteristics between grids with and without KLWR captures were only examined for young hammock, due to limited KLWR captures on old and medium hammock grids. Within young hammocks, KLWRs were present on grids with a more opened canopy and fewer Jamaican dogwood trees (Table 3.2).

Nest-site Selection

Seventeen (7 males, 10 females) trapped KLWRs were radio collared. KLWRs chose to nest in rock piles and garbage piles more often than in fallen logs and other nesting materials (Fig. 3.2). Furthermore, KLWR predominantly selected young hammock areas for their nest-sites. Forty nests were found in young hammock (13 male, 27 female), while only 5 (2 male, 3 female) were found in medium and 3 in old (3 male, Fig. 3.3).

Table 3.1. Summary of vegetative characteristics for KLWR habitat by age-class (young, medium, old), Key Largo, Florida, 2002.

Variable [a]	Age-class [b]	n	$\bar{x}$	SD	*P*
canopy	young	20	13.90	2.71	≤ 0.001
	medium	20	16.35	1.53	
	old	20	18.00	0.92	
std	young	20	164.20	35.35	0.026
	medium	20	155.45	30.11	
	old	20	134.85	36.69	
dbh	young	20	12.30	1.38	≤ 0.001
	medium	20	13.60	1.19	
	old	20	15.10	2.08	
ost	young	20	307.60	72.60	≤ 0.001
	medium	20	258.75	35.36	
	old	20	234.10	28.18	
ust	young	20	129.20	33.72	0.028
	medium	20	105.85	25.26	
	old	20	117.25	19.46	
log	young	20	1.45	0.69	0.002
	medium	20	2.30	0.92	
	old	20	2.75	1.33	
ma	young	20	1.40	1.96	0.374
	medium	20	2.10	2.20	
	old	20	2.20	2.44	
pp	young	20	1.90	2.27	≤ 0.001
	medium	20	6.50	3.80	
	old	20	8.50	5.74	
pw	young	20	5.45	4.47	0.102
	medium	20	6.75	5.01	
	old	20	8.45	5.09	
jd	young	20	3.50	4.15	0.303
	medium	20	2.55	2.31	
	old	20	1.65	1.98	
gl	young	20	5.45	3.09	0.192
	medium	20	5.70	3.16	
	old	20	4.10	3.45	
tam	young	20	7.90	7.39	≤ 0.001
	medium	20	1.90	2.75	
	old	20	0.55	1.40	

[a] canopy = percent canopy closure, ost = overstory tree density , dbh = overstory tree size, std = stem density, ust = understory tree density, logs = fallen log density: overstory trees, ma = mahogany, pp = pigeon plum, pw = poisonwood, jd = Jamacian dogwood,
gl = gumbo limbo, tam = tamarind.

[b] young (disturbed > 1971; 87 ha), medium (disturbed between 1940 –1971; 327 ha), and old (disturbed < 1940; 431 ha)

Table 3.2. Summary of vegetative characteristics for KLWR habitat in young hammock on 1-ha grids with and without KLWR captures, Key Largo, Florida, 2002.

Variable [a]	KLWR present	n	$\bar{x}$	SD	*P*
Canopy	no	12	14.83	2.44	0.044
	yes	8	12.50	2.62	
std	no	12	160.80	36.20	0.592
	yes	8	169.30	35.90	
dbh	no	12	12.75	1.42	0.094
	yes	8	11.63	1.06	
ost	no	12	302.10	56.50	0.670
	yes	8	315.90	95.80	
ust	no	12	133.30	36.40	0.643
	yes	8	123.00	30.50	
log	no	12	1.33	0.65	0.242
	yes	8	1.63	0.74	
ma	no	12	1.67	2.06	0.337
	yes	8	1.00	1.85	
pp	no	12	1.83	2.17	0.905
	yes	8	2.00	2.56	
pw	no	12	4.83	3.69	0.438
	yes	8	6.38	5.58	
jd	no	12	5.17	4.39	0.008
	yes	8	1.00	2.14	
gl	no	12	5.33	3.45	0.832
	yes	8	5.63	2.67	
tam	no	12	7.33	6.92	0.667
	yes	8	8.75	8.46	

[a] canopy = percent canopy closure, ost = overstory tree density , dbh = overstory tree size, std = stem density, ust = understory tree density, logs = fallen log density: overstory trees, ma = mahogany, pp = pigeon plum, pw = poison wood, jd= Jamacian dogwood,
gl = gumbo limbo, tam = tamarind.

Table 3.3. Pair-wise and nonparametric comparisons of vegetative characteristics found to be significant for KLWR habitat by age-class (young, medium, old).

Variable [a]	Comparison [b]	Test [c]	Test statistic	*P*
Canopy	old-medium	KW	h = 11.76	≤ 0.001
	medium-young	KW	h = 9.37	0.002
	old-young	KW	h = 23.27	≤ 0.001
std	old-medium	T	t = -1.906	0.14
	medium-young	T	t = 0.810	0.696
	old-young	T	t = 2.72	0.023
dbh	old-medium	KW	h = 5.14	0.023
	medium-young	KW	h = 8.58	0.004
	old-young	KW	h = 15.96	≤ 0.001
ost	old-medium	T	t = -1.578	0.236
	medium-young	T	t = 3.127	0.0077
	old-young	T	t = 4.705	≤ 0.001
ust	old-medium	T	t = 1.345	0.3763
	medium-young	T	t = 2.756	0.0211
	old-young	T	t = 1.410	0.3424
log	old-medium	KW	h = 1.25	0.279
	medium-young	KW	h = 8.09	0.004
	old-young	KW	h = 9.73	0.002
pp	old-medium	KW	h = 1.01	0.315
	medium-young	KW	h = 15.81	≤ 0.001
	old-young	KW	h = 16.7	≤ 0.001
tam	old-medium	KW	h = 4.67	0.031
	medium-young	KW	h = 7.32	0.007
	old-young	KW	h = 14.38	≤ 0.001

[a] canopy = percent canopy closure, ost = overstory tree density , dbh = overstory tree size, std = stem density, ust = understory tree density, logs = fallen log density: overstory trees, ma = mahogany, pp = pigeon plum, pw = poison wood, jd= Jamacian dogwood, gl = gumbo limbo, tam = tamarind.

[b] young (disturbed > 1971; 87 ha), medium (disturbed between 1940 –1971; 327 ha), and old (disturbed < 1940; 431 ha)

[c] T = Tukey’s W procedure , kw = Kurskal-Wallis

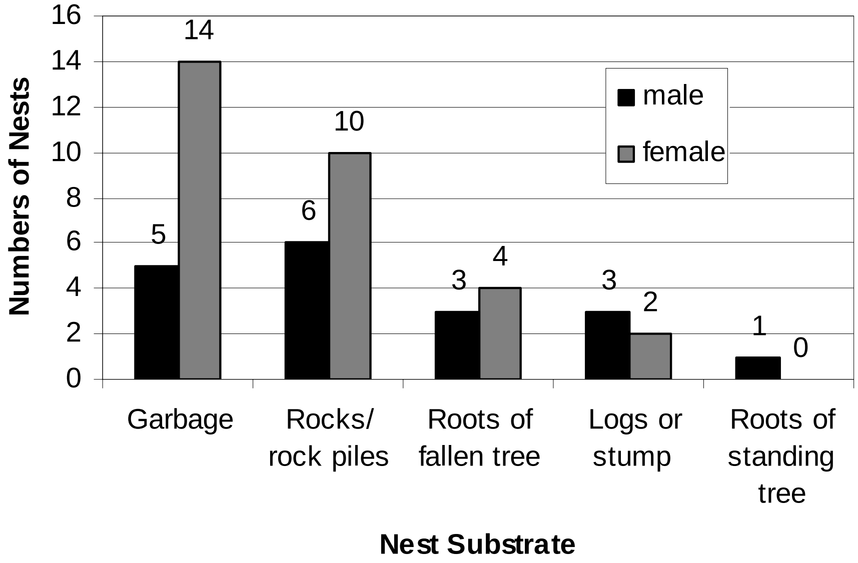

Figure 3.2. Frequency of KLWR nest-site selection by nest substrate and sex, Key Largo, Florida, 2002.

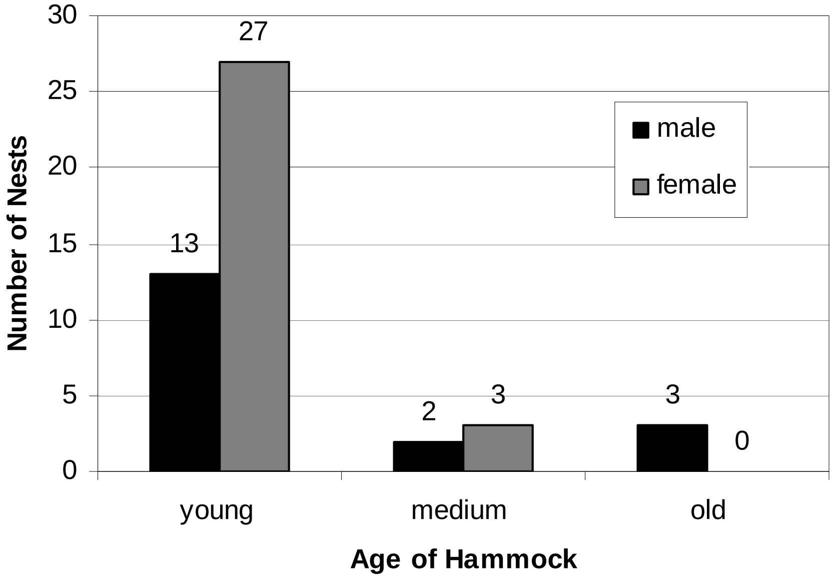

Figure 3.3. Frequency of KLWR nest-site selection by hammock age-class and sex, Key Largo, Florida, 2002.

DISCUSSION

Habitat Preferences

I found approximately 80% of all KLWR captures in young hammock areas, which challenges long held beliefs that KLWRs prefer mature hammock. My study found the KLWR population selected new and regenerating hardwood hammock. Young hammock stands were significantly different from medium and old forests in most vegetative characteristics. It is highly likely the KLWR was always abundant in young hammock, however because of its generally impenetrable nature and an acceptance of mature hammock as optimal habitat, previous researchers avoided trapping these areas.

Within young hammocks, KLWRs selected areas with a more open canopy. The KLWR's preference for open canopy is important because KLWRs have been shown to be arboreal and move throughout the forest canopy (Goodyear 1985). Moreover, open canopy is likely related to dense understory growth typically found within these areas. I have frequently observed captured and radio-collared KLWRs in areas with dense understories particularly near the edges of old roads and clearings. Unfortunately, my understory measurement (stem density) was not effective for measuring growth below shoulder level. The selection of young forest with open canopy and dense undergrowth was markedly different than reported by other studies (DOI 1973, Brown 1978, Hersh 1978, Barbour and Humphrey 1982). However, it was congruous with research on eastern woodrats in Florida and the Southeastern United States that showed higher trap success in ecotonal areas (Pearson 1952, Haysmith 1995) and higher densities of woodrats in areas of dense vegetation (Neal 1965, Haysmith 1995, Wilson 1999).

Nest-site Selection

The KLWR used trash, rock piles, roots, logs, and stumps as a nest substrate and were found to nest in young hammock over 83% of the time. Vines and thick undergrowth surrounded most of the nest-sites, and many of the nests were located on abandon road edges within piles of trash. Despite the KLWR's reputation as a stick-nest builder, the use of alternative nesting does not appear unusual. Studies have found eastern woodrats nest in human structures, garbage, rock crevices, and in dense tangles with a few sticks piled next to hollow logs, stumps, and cracks in ground (Pearson 1952, Fitch and Rainey 1956, Rainey 1956, Finely 1958, Greer 1978, Haysmith 1995, Wilson 1999). Humphrey (1992) believed rock piles and trash increased KLWR densities. Unfortunately, the KLWR recovery plan recommends the removal of trash (USFWS 1999), and piles of trash once common on utility right of ways in north Key Largo have since been removed. During the clean-up of many of these areas, garbage piles were found to contain active woodrat nests (D. A. Shaw, Florida Keys Electric Cooperative Association, personal communication).

MANAGEMENT IMPLICATIONS

It appears that young hammock areas are important to the KLWR. Young hammocks in the study area are isolated in small patches and comprise the smallest portion of hammock age-classes (87 ha, 10.3 %). KLWRs use of this fragmented young forest along with indications it may be using edge habitat could be a potential problem for the species. Studies have shown increased predation of woodrats and other small mammals on forest edges (Metzgar 1967, Sakai and Noon 1997). Additionally, young fragmented habitat may be more susceptible to the infiltration of fire ants, which is believed to be a potential problem for the KLWR (Frank et al. 1997).

Given the KLWRs habitat and nesting preferences, I recommend the creation of large patches (> 20 ha) of young hammock bordering on old or medium hammock areas to buffer and protect these areas. I would create these areas through burning, clearing, or other restoration practices. Enhancement and creation of young forest for KLWRs might include increasing nesting sites through the addition of hollow logs, piles of large rocks, and even old cars. Additionally, I recommend restoring old roads that bisect young forest to create larger contiguous patches of young hammock. Study results do not suggest that old or medium hammocks areas are not useful to the KLWR. To the contrary, if the KLWR is to recover older hammock areas would be essential during re-colonization by the woodrat.

CHAPTER IV

RACCOON ROUNDWORM: A FACTOR IN THE DECLINE OF THE KEY LARGO WOODRAT?

SYNOPSIS

The endangered Key Largo woodrat (KLWR, *Neotoma floridana smalli*) population has been declining for the last 25 years. Numerous factors have been proposed to explain the precipitous decline of the KLWR, including feral cat (*Felix domestica*) predation, habitat fragmentation, fire ant (*Solenopsus spp*.) predation, and competition with black rats (*Rattus rattus*). Recent studies indicated that raccoon roundworm (*Baylisascaris procyonis*) had an adverse effect on the survival of the Alleghany woodrat (*N. magister*). Raccoons (*Procyon lotor*) serve as a primary host for the nematode. High densities of raccoon can exacerbate the potential problem by making infected feces readily available to wildlife. Initially, I believed the highly visible raccoon presence in KLWR habitat made infection by *B. procyonis* a viable alternative hypothesis for explaining the KLWR population decline. In 2002, I estimated a raccoon density on Key Largo, Florida, of 0.62 raccoons/ha. From the raccoon population, I sampled 64 raccoon fecal samples to determine the presence of *B. procyonis* eggs. All samples were found to be negative. I concluded that despite the perceived threat of *B. procyonis* to the KLWR population, the raccoon roundworm is not a likely factor contributing to the decline of the woodrat numbers on Key Largo**.**

INTRODUCTION

The endangered Key Largo woodrat (KLWR) is a federally-listed sub-species endemic to Key Largo, Florida. Since 1973, the KLWR has been confined to approximately 850 ha of tropical hardwood hammock forest on the northern third of the island (Fig. 1.1, U.S. Department of the Interior [DOI] 1973, Barbour and Humphrey 1982, U.S. Fish and Wildlife Service [USFWS] 1999). The majority of KLWR habitat is within the bounds of 2 protected areas: Dagny Johnson Key Largo Hammock Botanical State Park and Crocodile Lake National Wildlife Refuge (Frank et al. 1997). Population trend data from trapping suggests a precipitous decline in the population with current estimates between 26 and 106 individuals (Chapter II). A Population Viability Analysis (PVA) predicts a high (>95%) probability of extinction for the KLWR in the next 10 years (Chapter V) if no management actions are taken. Numerous unsubstantiated hypotheses including feral cat predation (Humphrey 1992, Frank et al. 1997, USFWS 1999), fire ants (Frank et al. 1997), habitat fragmentation (Goodyear 1985, Frank et al. 1997, USFWS 1999), competition with black rats (Hersh 1981, Humphrey 1992, Frank et al. 1997, USFWS 1999), disease (USFWS 1999), and a combination of the above have been suggested as the causes of the KLWR's decline (Frank et al. 1997). Direct evidence of specific limiting factors, however, is lacking.

Recent studies by McGowan (1993) and LoGiudice (2001, 2003) indicate *B. procyonis*, a common parasitic nematode found in the small intestine of raccoons (Kazacos 2001), had adverse effects on the survival of the endangered Alleghany woodrat. Eggs of *B. procyonis* can pass via raccoon fecal matter where they can be ingested by woodrats or other wildlife. Once ingested by an intermediate host, an embryonated *B. procyonis* egg can become highly pathogenic and is often fatal to small mammal species (Kazacos 2001, LoGiudice 2003). Numerous rodents including woodrats feed on undigested seeds found in raccoon feces (Page et al. 2001, LoGiudice 2001). Furthermore, the behavior of woodrats makes them highly susceptible to ingesting the eggs of *B. procyonis* and thereby becoming infected. For example, woodrats collect fecal matter and store them in food caches where *B. procyonis* eggs can contaminate food supply (LoGiudice 2001). Additionally, woodrats may wait several weeks for fecal matter to harden before harvesting it, allowing the parasite's eggs time to embryonate and become potentially dangerous (LoGiudice 2001). High densities of raccoons appear to increase the abundance and threat of *B. procyonis* to woodrats (LoGiudice 2003). It was the purpose of my study to: (1) determine the prevalence of *B. procyonis* eggs in the feces of raccoons on Key Largo, (2) estimate raccoon densities on north Key Largo, and (3) determine what risk *B. procyonis* poses to the remaining KLWR population.

METHODS

Study Area

Key Largo is the first and largest in a chain of islands (keys) that extend from the southern tip of Florida. My study area on Key Largo was limited to KLWR habitat (845 ha) found along an 11-km stretch of protected hardwood hammock forest on the northern third of the island (Fig. 1.1). Hardwood hammock habitat is unique, with a high abundance of West Indian plants and trees (Strong and Bancroft 1994, USFWS 1999).

Some common trees found in Key Largo's hammocks are gumbo-limbo (*Buresa simaruba*), poisonwood (*Metopium toxiferum*), wild tamarind (*Lysiloma bahamensis*), pigeon plum (*Cocoloba diversifolia*), willow bustic (*Bumelia salicifolia*), and Jamaican dogwood (*Piscidia fostidissimum*).

Raccoon Trapping

Raccoons were trapped within existing KLWR habitat to determine the presence of *B. procyonis* between June-October 2002. The study area (845-ha) was divided into 28-ha blocks. Within each block, approximately 4 traps (Tomahawk 106 and 108 live-traps, Tomahawk, Wisconsin) were set and baited with dry cat food (9 Lives, Heinz Company, Pittsburgh, Pennsylvania) for a period of 2-3 days. Trapping ceased once a raccoon was captured and a fecal sample was collected within each block. A total of 30 (28-ha) blocks were trapped between June-September 2002.

In November 2002, an attempt to obtain an estimate of raccoon density was conducted on a 132-ha tract of hardwood hammock surrounded by water and a major highway. This area was selected because (1) a large portion (≈ 40%) of KLWRs were found within this area and (2) raccoon dispersal was limited (area "closed"). Within this area, approximately 40 traps (Tomahawk 106 and 108 live-traps, Tomahawk, Wisconsin) were placed 150-m apart along transects and baited with dry cat food (9 Lives, Heinz Company, Pittsburgh, Pennsylvania) for a period of 12 days. Captured raccoons were marked with colored PVC cement on the right-side if a fecal sample was collected; otherwise the left-side was marked. Raccoon densities were estimated using a Schnabel method (Krebs 1999).

Parasite Counts

Fecal samples were prepared using a modified centrifugal flotation technique (Sloss et al. 1994) with sodium nitrate solution. Each sample (>70g) was centrifuged for 10 minutes and flotations were examined for raccoon roundworm eggs (Sloss et al. 1994).

RESULTS

Fecal samples were collected from 64 individuals. All samples tested negative for *B. procyonis* eggs. I estimated the raccoon density for north Key Largo to be approximately 0.62 raccoons/ha (95% CI = 0.38-1.21 raccoons/ha).

DISCUSSION

My study suggested that the raccoon roundworm has not contributed to the decline of the KLWR population. In the sampling of *B. procyonis* eggs in the raccoon population, all fecal samples tested negative.

Other studies have documented sparse densities of *B. procyonis* in the southeastern U. S. (Kazacos 2001) with no recorded observations in Florida (Forester 1992, Kazacos 2001). According to Kazacos (2001), the absence of raccoon roundworm in many southeastern states was not caused by environmental factors; instead, the roundworm was not present in the raccoon populations that colonized those areas. High raccoon densities would be a concern in spreading the nematode if *B. procyonis* were to be accidentally introduced into the area. The density of raccoon in Key Largo (0.62 raccoons/ha) was high compared to other reported raccoon densities (0.2 raccoons/ha) in similar habitats (Wilson and Rue 1999). Continued monitoring for *B. procyonis* is recommended as recovery efforts for the species continue.

CHAPTER V

RANGES AND MOVEMENTS OF THE KEY LARGO WOODRAT

SYNOPSIS

Little is known about the movements of the endangered Key Largo woodrat (KLWR, *Neotoma floridana smalli,*), and to date an intensive radio telemetry study has never been conducted on the KLWR. Range and movement data are important in the recovery of the species. They aid in determining the amount of habitat necessary for KLWR introduction, social interaction, barriers to movements, and providing baseline data for future studies of introduced KLWRs. Sixteen (6 male, 10 female) KLWRs were trapped, radio-tagged, and tracked from March–November 2002, recording a total of 631 locations. I examined differences in average monthly ranges, and seasonal ranges of KLWRs together and by sex. The average monthly ranges of male and female KLWRs were significantly different ($P = 0.032$) at 0.48 (95% CI = 0.24-0.71) ha and 0.21 (95% CI = 0.11-0.30) ha, respectively. Six female ranges overlapped an average of 49% and 2 males overlapped an average of 8%. County Road 905 appears to be a barrier to KLWR movements.

INTRODUCTION

The endangered Key Largo woodrat (KLWR) is endemic to the island of Key Largo, Florida. In 1984, it was classified as a federally endangered species because of concerns over habitat loss and the impact of commercial development (U. S. Department of Interior [DOI] 1984). Forty-seven percent of the KLWR's tropical hardwood hammock habitat has been lost from the island and most of what remains has been cleared, thinned, developed, and fragmented (Strong and Bancroft 1994). Since 1973, the KLWR has been confined to approximately 850 ha of remaining forest on the northern third of Key Largo (DOI 1973, Barbour and Humphrey 1982). Most of these 850 ha are within the bounds of 2 protected areas: the Dagny Johnson Key Largo Hammock Botanical State Park and the Crocodile Lake National Wildlife Refuge (Frank et al. 1997). Still, even within these protected areas the KLWR has suffered from at least 2 decades of decline (Chapter II). Population trend data from trapping suggests a precipitous decline in the population with current estimates between 26 and 106 individuals (Chapter II). In 2003, the U. S. Fish and Wildlife Service (USFWS) commenced efforts for a captive breeding program for the KLWR. One of the primary goals of the program is to release captive-reared KLWRs into suitable native habitat (Dean 2003).

Little is known about the movements of the KLWR, leaving managers with little information to make vital decisions on the reintroduction and recovery of this species. Pervious studies (Hersh 1981, Sasso 1999) have used trapping grids to estimate KLWR ranges and movements, however, the limitations of these methods have been well documented (Stickel 1954, Sanderson 1966). To date, there has never been an intensive radio-telemetry study conducted on the KLWR. Estimates of ranges and movements from telemetry are essential to KLWR conservation to: (1) determine the amount of habitat required for the reintroduction of captive reared KLWRs, (2) determine social interactions vital in captive breeding, (3) determine barriers to KLWR movements (e.g. roads), and (4) provide baseline data needed to compare the future movements of introduced KLWRs to resident populations. I estimated KLWR ranges, and examined the effect of sex, month, and season on range size. I also examined if County Road 905 (a heavily used road that bisects KLWR habitat, Fig. 5.1) was a barrier to KLWR movements.

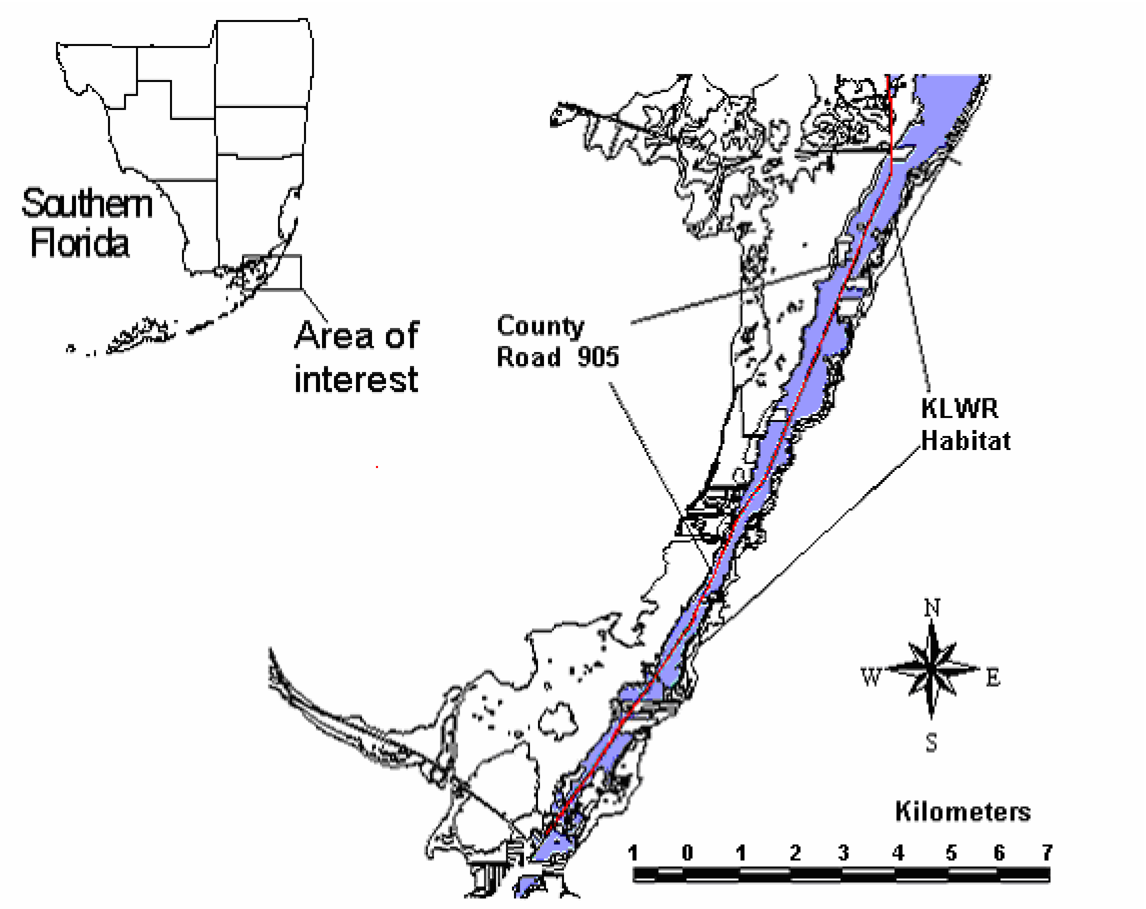

Fig. 5.1. The northern third of the island of Key Largo, Florida, KLWR habitat and County Road 905.

METHODS

KLWRs were trapped from March–September 2002 and radio-tagged with 7-g radio collars (AVM Instrument Company, Colfax, California) with mortality sensors (Model G3). They were located twice weekly during daylight hours at their nesting sites and at least twice a week at night during 1of 3 random, 3-hour intervals (2000- 5000). Locations were determined via homing and triangulation (Samuel and Fuller 1996). Homed locations were recorded with a Global Positioning System (GPS; Magellan 315) and mapped on a Geographical Information System (GIS). Three or more bearings from known receiving stations (determined from a GPS) were used to calculate triangulated locations. I generated XY-coordinate locations and error ellipses using LOAS (Location of a Signal, Ecological Software Solutions, Urnäsch, Switzerland) and mapped them on a GIS. Triangulated locations with error ellipses > 500 m^2 were disregarded.

The acceptable number of telemetry locations necessary for the calculation of KLWR ranges was calculated using BIOTAS (Ecological Software Solutions, Urnäsch, Switzerland) to plot the total range area of individual KLWRs versus the number of locations on the animal. The number of locations it took for the range area of most KLWR ranges to plateau was chosen as the number of locations needed to calculate a KLWR range. BIOTAS was then used to determined 100% minimum-convex polygons (MCP) for KLWRs by month. From monthly MCP range sizes, I calculated average monthly ranges and seasonal ranges (averages from 3-month periods; spring = March–May; summer = June–August; fall = September–December). Differences in male and female average monthly and seasonal ranges were evaluated, and differences between seasonal ranges were evaluated for the combined population. Normally distributed data were analyzed with general linear models ($P < 0.05$) (Ott 1993), and non-normal data with a Kurskal-Wallis test ($P < 0.05$) (Ott 1993).

Range Overlap

The percentage of range overlap was calculated between and within sexes from KLWRs tracked during similar time periods. Overlap was determined by dividing the amount of intersected area from both KLWRs by the range area of each individual. ArcView (Environmental Systems Research Institute, Redlands, California, USA, version 3.1) and the ArcView animal movements extension (Version 2.2; Hooge and Eichenlaub 1999) were used to place monthly MCP ranges on a GIS database. The amount of area intersected was calculated using ArcView geo-processing tool.

Roads

All KLWR locations were placed on a GIS database with roads and DOQQ (digital ortho quarter quads) of north Key Largo, to determine weather KLWRs crossed County Road 905 and, if so at what rate. I recorded KLWR locations within 25 m of the road and the number of times consecutive locations were found on opposite sides of the road. Rates of crossing were calculated as the number of consecutive locations on opposite sides of the road by the number of locations within 25 m of the road. Mortalities from road kill were determined by examining recovered radio collars and the sites of mortality where the transmitters were located.

Table 5.1. Average MCP monthly and seasonal KLWR range sizes by sex, Key Largo, Florida.

Range	time period	sex	*n* KLWRs	*n* monthly averages	$\bar{x}$	median	SE
Average monthly	all records	female	10		2,051	1,245	480
		male	6		4,756	3,900	1,190
		both	16		3,065	2,542	615
Seasonal [a]	spring	female		9	1,126	480	427
	summer			11	1,076	677	344
	fall			17	2,414	2,212	408
	spring	male		3	8,060	3,219	5,185
	summer			3	9,945	8,632	4,454
	fall			5	3,979	3,606	1,196
	spring	both		12	2,859	1,294	1,463
	summer			14	2,976	749	1,321
	fall			23	2,744	2,216	407

[a] spring = March–May; summer = June–August; fall = September–December

Table 5.2. Differences in monthly and seasonal MCP KLWR ranges by sex and season, Key Largo, Florida.

Model	Variable	Test statistic	df	p
average monthly range	sex	F=6.07	1,14	0.027
seasonal range all KLWRs	season	H=3.27	2	0.195
female seasonal range [a]	season	H=6.88	2	0.032
male seasonal range [a]	season	F=.97	2,8	0.423
spring seasonal range [a]	sex	H=4.52	1	0.033
summer seasonal range [a]	sex	H=5.10	1	0.024
fall seasonal range [a]	sex	F=2.77	1,21	0.111

[a] spring = March–May, summer = June–August, fall= September–December

RESULTS

Sixteen KLWRs (10 female, 6 male) were radio-collared and tracked March-November 2002. A total of 631 locations were recorded. I determined that at least 9 locations were necessary to calculate a KLWR range, from range area vs. location plots. The average monthly ranges of individual male and female KLWRs were 4,756 (95% CI = 2,376-7,136) m^2 and 2,051 (95% CI = 1,091-3,011) m^2,respectively (Table 5.1). I found male and female ranges to be significantly different *(P* = 0.032, Table 5.2). Female ranges varied with season (*P*= 0.032), while male ranges did not (*P*= 0.567). Spring (*P*= 0.033), and summer (*P*= 0.019) ranges were significantly different between sexes and fall ranges were not (*P*= 0.111).

Range Overlap

The ranges of 1 male and female KLWR overlapped, 11% for the male and 27% for the female. Six female ranges overlapped an average of 49% and 2 males overlapped an average of 8%.

Roads

Six KLWRs were located within 25 m of County Road 905 on 38 occasions, but I recorded no KLWRs with locations on both sides of the road. From 6 KLWR mortalities, none were found on or near the road.

DISCUSSION

Male KLWRs had larger average monthly ranges and larger ranges than females in both spring and summer. Female KLWRs ranges were smaller in the spring and summer than the fall. Larger ranges for KLWR males were observed by Sasso (2002), but not by Hersh (1981). I believe the seasonal shifts in range sizes were due to the reproductive cycles of the KLWR. It is probable that males extended their ranges (relative to females) in search of mates when they were sexually active in the spring and summer. Conversely, females condensed their ranges for the care and suckling of young. Cranford (1977) associated the seasonal changes in *N. fuscipes* ranges to reproductive activity. Research on KLWRs (Hersh 1981, Sasso 1999) and other *N. florinana spp*. (Hamilton 1953, Haysmith 1995) have genererally shown that eastern woodrat sexual activity peaks in the spring and summer.

My research suggested that KLWR ranges were smaller than those of *N. f. floridana* (Haysmith 1995). It also has been shown that KLWRs select for patches of young forest that are often small and fragmented (Chapter III). Possibly the KLWR ranges were relatively small because they were isolated areas of young forest. However, telemetry data from KLWRs indicated males would occasionally leave patches of young hammock for older hammock, possible in search of females. To determine whether the KLWR ranges are relatively small because they are isolated in small patches of suitable habitat, or because they are small because they are using quality habitat, I would recommend the creation of large patches (>20 ha) of young forest (Chapter III). Once KLWRs are established or introduced in these areas, I would examine the differences in ranges and population demographics between KLWR in the newly created habitat and the currently used habitat.

Range Overlap

Female KLWRs appeared socially tolerant of each other, overlapping ranges an average of 49%. On numerous occasions, I found 2 female KLWRs (possibly related) out of their nests at night and in close proximity to each other. Still, I never found 2 adult KLWRs sharing a nest during daytime hours. Males appeared to be intolerant of one another. Only 2 male ranges overlapped an average of 8%. It may prove important for the captive breeding and reintroduction of KLWRs to insure that males are separated in captivity and given ample space when reintroduced. I would recommend that males be placed at least 110 m apart (the approximate diameter of their spring and summer range, assuming ranges are circular). Data from the also suggest it may be beneficial to hold and reintroduce related females in close proximity to each other (20 m) so long they are provided separate nesting sites.

Roads

I did not find County Road 905 to be a source of KLWR mortality. However, County Road 905 does appear to create a barrier to woodrat movement. At the KLWR's currently low densities, I believe this problem may be minimal, but if the population rebounds the road could be a cause for concern and may require management action.

CHAPTER VI

VIABILITY OF THE KEY LARGO WOODRAT

SYNOPSIS

The endangered Key Largo woodrat (KLWR, *Neotoma floridana smalli*) population has been declining for the last 2 decades with current estimates between 26 and 106 individuals. In 2003, the U. S. Fish and Wildlife Service (USFWS) began a captive breeding program with a goal of augmenting the wild population in Key Largo, Florida. I conducted a population viability analysis (PVA) using Ramas METAPOP for the KLWR. I used trapping and telemetry data along with published and unpublished KLWR data to estimate demographic parameters used in the model. With the KLWR model, I evaluated the effectiveness of woodrat introduction *a priori* and identified areas for future research. Model simulations suggested the KLWR, even with annual introductions (≤ 20 females), had a high risk of extinction within the next 10 years. Model results illustrated the importance of determining KLWR limiting factors prior to planned reintroductions.

INTRODUCTION

The endangered Key Largo woodrat (KLWR) is a federally-listed sub-species endemic to Key Largo, Florida. Since 1973, the KLWR has been confined to approximately 850 ha of tropical hardwood hammock forest on the northern third of the island (U.S. Department of the Interior [DOI] 1973, Barbour and Humphrey 1982, U. S. Fish and Wildlife Service [USFWS] 1999). Most of these 850 ha are within the bounds of 2 protected areas: the Dagny Johnson Key Largo Hammock Botanical State Park and the Crocodile Lake National Wildlife Refuge (Frank et al. 1997). Still, even within these protected areas the KLWR has suffered from at least 2 decades of decline (Chapter II). Population trend data suggests a precipitous decline in the population with current estimates between 26 and 106 individuals (Chapter II). In 2003, the USFWS commenced efforts for a captive breeding program for the KLWR. One of the primary goals of the program is to release captive-reared KLWRs into suitable native habitat (Dean 2003).

A population viability analysis (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 1989). Some other advantages of structured models include the ability to incorporate variation (environmental stochasticity) in vital rates, the effect of population size (density dependence), and differences in discrete populations (Akcakaya 2000).

Compared to other alternatives for making conservation decisions, PVAs provides 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). For these reasons a stage-structured population for the KLWR was developed to: (1) estimate the KLWR's risk of extinction, (2) evaluate effectiveness of KLWR releases *a priori*, and (3) conduct a sensitivity analysis to identify model parameters which account for the greatest uncertainty to plan future field research.

METHODS

Study Area

Key Largo is the first and largest in a chain of islands (keys) that extends from the southern tip of Florida. Our study area on Key Largo was limited to KLWR habitat (845 ha) found along an 11-km stretch of protected hardwood hammock forest on the northern third of the island (Fig. 1.1). Hardwood hammock habitat on the island of Key Largo is unique with a high abundance of West Indian plants and trees (Strong and

Bancroft 1994, USFWS 1999). Some common trees found in Key Largo's hammocks are gumbo-limbo (*Buresa simaruba*), poisonwood (*Metopium toxiferum*), wild tamarind (*Lysiloma bahamensis*), pigeon plum (*Cocoloba diversifolia*), willow bustic (*Bumelia salicifolia*), and Jamaican dogwood (*Piscidia fostidissimum*).

Model Overview

I used Ramas METAPOP (Akcakaya 1998) to conduct PVA using a stage-structured, stochastic population model. I considered the KLWR population as a single population comprised of juveniles (< 6 months) and adults (> 6 months) and modeled female KLWRs in the PVA. Juvenile recruitment was defined at the end of each simulation period. In addition to a baseline simulation (no captive-raised KLWR releases), I evaluated the effect of the captive-raised KLWR releases to the overall population viability. Model results were summarized in terms of population trajectories and risks of terminal extinction (Akcakaya 2000).

Model Demography

I used trapping and telemetry data (Chapters II and V) along with published and unpublished KLWR data to estimate model parameters. Where data were incomplete or sparse, I used published data on other *N. floridana spp*.

Survival. —Annual adult survival estimates and standard deviations were determined using a Mayfield estimator (Krebs 1999) from radio-telemetry data collected between March–December 2002. Adult survival rates also were calculated from trapping data (Frank et al. 1997, Sasso 1999) using a Jolly-Seber estimator (Krebs 1999).

I calculate juvenile survival rates and standard deviations using trapping data (Frank et al. 1997; USFWS, unpublished data 2000), and validated these estimates by comparing them to other juvenile survival rates (Rainey 1956).

Fecundity. —I used a sex ratio of 56% females from trapping data (Chapter II). Maternity (number of embryos and litters produced annually) was taken from published accounts of *N. floridana* (Fitch 1956). From these estimates, I determined fecundity for KLWR adults as ($F = R * M * S_a$) where R was equal to female sex ratio, M was equal to maternity, and S_a was adult survival. Fecundity variance was determined as described by Burgman et al. (1993) where variance of the product of two values (1 and 2) was given by

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

Mean, variance, and coefficient of variation estimates for maternities (1) and survivorships (2) were used in this formula. KLWR juveniles are not sexually active (Hersh 1981) and did not contribute to young in the model.

Stage Structure.— I modeled the female KLWR populations using a 2-stage matrix model (juvenile, adult). The stage matrix of the model was,

$$\begin{matrix} & Fa \\ Sj & Sa \end{matrix}$$

where *Fa* was adult fecundity and *Sj* and *Sa* were juvenile and adult survival, respectively.

Initial Abundances.— Initial abundances were estimated from trapping and trend data population estimates (Chapter II). The high initial abundance estimate was calculated to be slightly higher than the 95% confidence interval (CI) from the 2002 trapping data (Chapter II), the medium estimate was generated by averaging population estimates (Chapter II), and the low estimate was taken from the lowest 2002 population estimates. I assumed a stable-age distribution for my simulations.

Environmental and Demographic Stochastisity.— I incorporated both demographic stochastisity (natural changes in births, deaths, and sex ratios) and environmental stochastisity (changes in the environment over time such as rainfall, food availability, fires, etc.) into the model. I incorporated demographic stochastisity in model simulations by sampling the number of survivors from a binomial distribution and the number of offspring from a Poisson distribution (Akcakaya 1991). I modeled environmental stochastisity 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).

Woodrat Reintroductions.— I evaluated 3 levels of KLWR augmentation: 5, 10, and 20 female KLWRs reintroduced annually from the captive breeding program. For each scenario, KLWRs were introduced from year 1-5.

Model Use

Density independence provides a conservative assessment in situations where there is a lack of information like that for the KLWR (Ginzburg et al. 1990). Thus, I modeled the KLWR population using the exponential growth option in Ramas Metapop.

For each scenario, I ran 10,000 simulations for 10 years. I varied the aforementioned variables while holding others constant to identify sensitive variables in the KLWR model (Table 6.1, Akakaya 2000). Model scenarios were as follows:

1. Scenario 0 (S0) = no change
2. Scenario 5 (S5) = introduction of 5 female KLWRs yearly for 5 years
3. Scenario 10 (S10) = introduction of 10 female KLWRs yearly for 5 years
4. Scenario 20 (S20) = introductions of 20 female KLWRs yearly for 5 years

I used 2 criteria to assess KLWR viability: population trajectory and risk of terminal extinction. To validate the model, I simulated population trends with density estimates from 1996 trapping data (759 female KLWRs, Frank et al. 1997) and compared simulated results to actual population trends (Chapter II).

RESULTS

KLWR Viability

All 4 scenarios simulated with low, medium, and high parameters yielded an average KLWR population size of < 20 individuals by the end of the simulation period (10 years) (Fig. 6.1). Even with a high number of captive-reared KLWR releases (e.g., 20 females yearly) population numbers declined when introductions ceased at year 5. The risk of terminal extinction was high (>95%) for all scenarios using low and medium parameters without introduction (Table 6.2). Using high parameter estimates and introductions, the risk of terminal extinction was decreased (<5%, Table 6.2).

Table 6.1. Low, medium, and high parameter estimates used in population viability analysis for KLWR population.

Parameter	Low	Medium	High
Survival	*Age = mean* Juvenile = 0.11 Sj Adult = 0.17 Sj	*Age = mean* Juvenile = 0.25 Sj Adult = 0.247 Sa	*Age = mean* Juvenile = 0.32 Sj Adult = 0.32 Sa
Survival SD	*Age= survival SD* Juvenile = 0.09 Adult = 0.09	*Age= survival SD* Juvenile = 0.06 Adult = 0.06	*Age= survival SD* Juvenile = 0.03 Adult = 0.03
Fecundity	*Age = maternity* Juvenile = 0.000 Adult = 0.338	*Age = maternity* Juvenile = 0.000 Adult = 0.547	*Age = maternity* Juvenile = 0.000 Adult = 0.810
Fecundity SD	Not varied	*Age = fecundity SD* Adult = 0.186 Average (10% CV)	Not varied
Initial Abundances	*Age = initial abundance* Juvenile = 5 Adult = 13	*Age = initial abundance* Juvenile = 11 Adult = 28	*Age = initial abundance* Juvenile = 33 Adult = 85
Reintroduction	*Age = no. introduced* Adult = 5 females	*Age = no. introduced* Adult = 10 females	*Age = no. introduced* Adult = 20 females

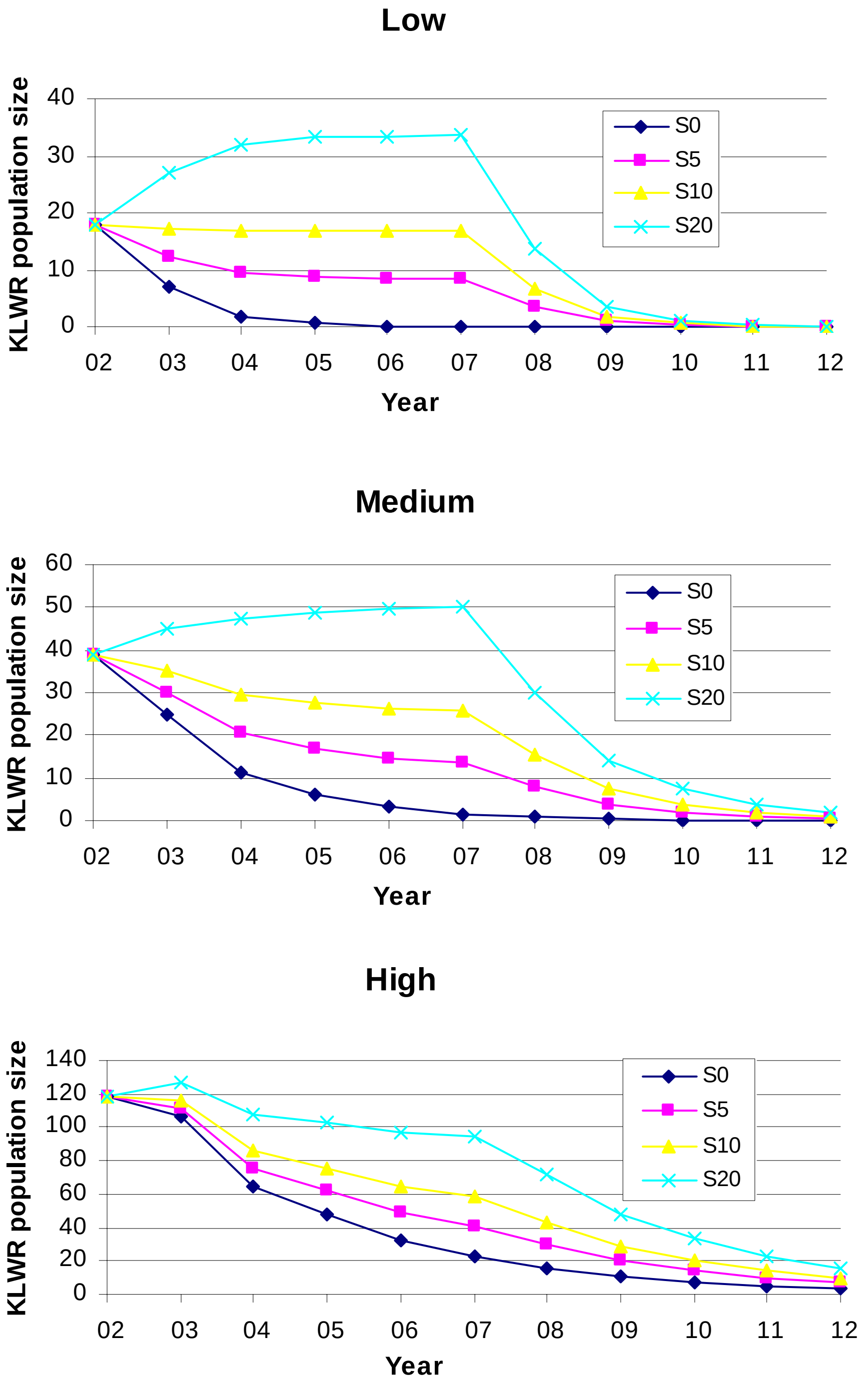

Fig. 6.1. Population trajectories for simulations of the KLWR population with varying numbers of introductions (0 females [S0], 5 females [S5], 10 females [S10], and 20 females [S20]) using low, medium, and high parameter estimates, Key Largo, Florida, 2002-2012.

Sensitivity Analysis

Sensitivity analysis showed initial population estimates and fecundity (Fa) to be the most sensitive parameters with (>0.0865) (Fig. 6.2). Whereas standard deviation estimates of juvenile and adult survival showed almost negligible (<0.0015) changes in the risk of terminal extinction. Future research should be directed at improving the former estimates.

Model Validation

Model simulations using 1996 population estimates yielded average 2002 populations of 100 (SD = 40.31), 16 (SD = 13.64), and 0.63 (SD= 1.63) using high, medium, and low parameters, respectively (Fig. 6.3). Actual population estimates from 2002 trapping data were similar (4.3-98.3 female KLWRs, Chapter II, Fig 6.3) to simulated results.

Table 6.2. Summary of terminal extinction risks (mean 95% ± CI) for population by management scenarios using low, medium and high parameter estimates, Key Largo, Florida, 2002-2012.

	Low		Medium		High	
Scenario	$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI
S0	0.9999	± 0.0089	0.9643	± 0.0089	0.2040	± 0.0089
S5	0.9824	± 0.0089	0.7135	± 0.0089	0.0380	± 0.0089
S10	0.9669	± 0.0089	0.5380	± 0.0089	0.0121	± 0.0089
S20	0.9377	± 0.0089	0.3460	± 0.0089	0.0020	± 0.0089

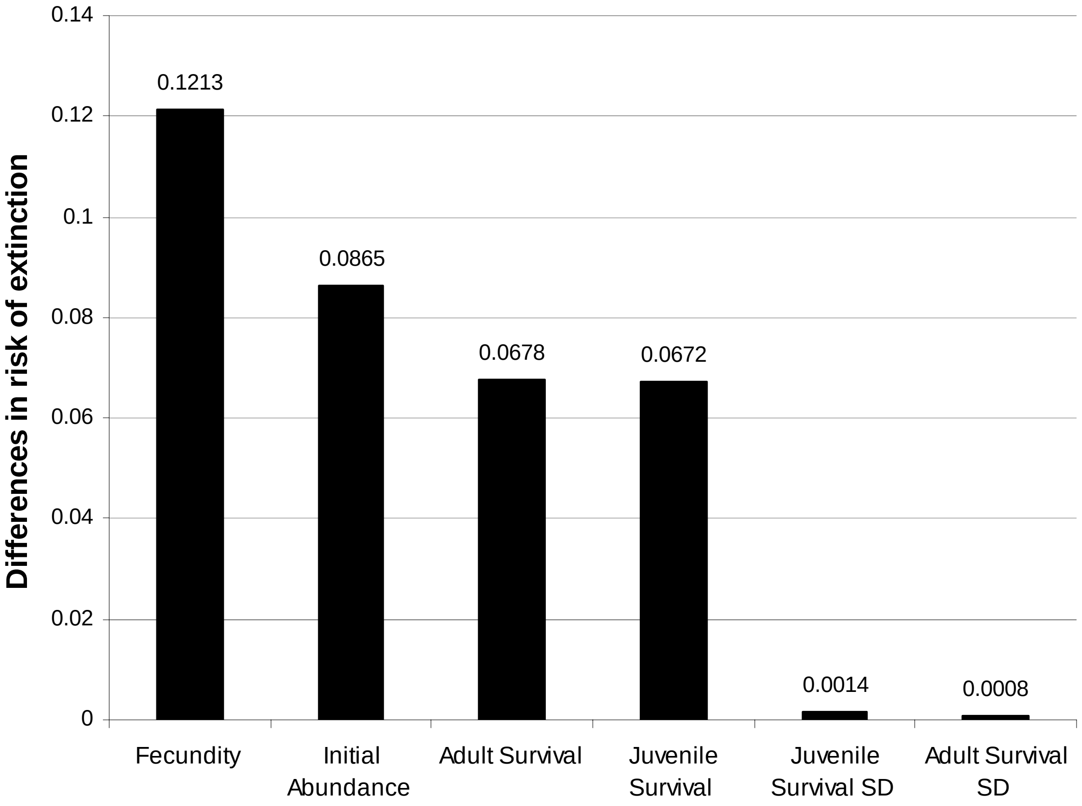

Fig. 6.2. Sensitivity analysis (difference in risk extinction between high and low parameter values) of model results to 6 parameters for the KLWR population, Key Largo, Florida, 2002.

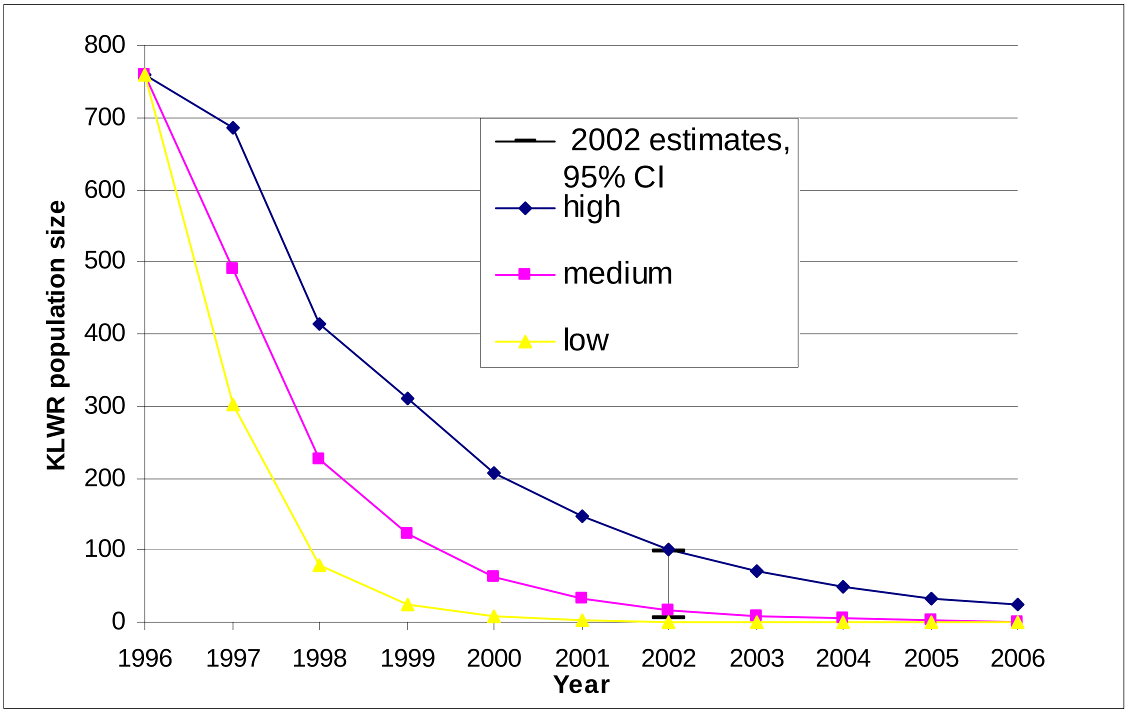

Figure 6.3. Simulated population trajectories for the KLWR population using low, medium, and high parameter estimates from 1996–2006. Note, 2002 KLWR population estimates.

DISCUSSION

KLWR Viability

The KLWR is at high risk of extinction with the model predicting extinction of the species within 10 years (Fig. 6.1, Table 6.2). Captive breeding and the introduction of KLWRs into the wild population may be an effective management tool if optimistic parameter values prove to be accurate. For example, KLWR introductions substantially reduced the risk of terminal extinction when the model was run with high parameters (Table 6.2), and introductions of 20 females annually (S20) allowed the population to grow under low and medium parameters (Fig. 6.1). Once introductions ceased, however, the KLWR population eventually declined to extinction (Fig. 6.1) illustrating the need to determine current limiting factors of KLWR prior to reintroduction. The model also assumes the KLWRs necessary for breeding will not be removed from the wild population, and introduced KLWRs will have the same survival and fecundity rates as the wild population. These assumptions probably have over estimated the effectiveness of introductions.

Sensitivity Analysis

I found initial abundance, adult survival, juvenile survival, and fecundity resulted in the greatest difference in the model output. Better estimates for these parameters would obviously improve the accuracy of the KLWR model. This can be accomplished via field research and monitoring of captivity-bred KLWRs.

Management and Research

To improve the accuracy of the PVA and to enhance its effectiveness as a management tool, I make several recommendations. I recommend continuous monitoring of the population size with the trapping protocol used to obtain trend data (Chapter II) and the addition of transects throughout north Key Largo. With the same amount of effort, transects have been shown to be more effective than grids at capturing small mammals at low densities (Pearson and Ruggiero 2003). I would monitor nests of sexually active KLWR females in an attempt to trap, radio tag, and estimate juvenile survival. Maternity data should be collected from females in captivity and incorporated into the KLWR model. Lastly, I believe future model improvement would be beneficial in evaluating management strategies in the recovery of the KLWR.

CHAPTER VII

CONCLUSIONS

From previous work, current population estimates, and a population viability analysis (PVA), there is strong evidence that the Key Largo woodrat (KLWR*, Neotoma floridana smalli*) is headed to extinction. Declines in stick-nest densities, trap success, and KLWR density estimates over the last 25 years points to a steady decline in the population. This perceived decline is supported by current population estimates from 2002 and 2003, which indicated less than 50 KLWRs for 4 of the 5 trapping sessions. A population viability analysis (PVA) predicted the KLWR was at a high (>95%) risk of extinction over the next 10 years when low and medium level population demographic data estimates were used. During PVA model simulations, only the introduction of 20 female KLWRs annually resulted in limited growth in the KLWR population.

Contrary to published reports (DOI 1973, Brown 1978, Hersh 1978, Barbour and Humphrey 1982, Goodyear 1985, U. S. Fish and Wildlife Service [USFWS] 1999), data from this study suggests KLWRs prefer to use and nest in young forest. Unfortunately, young forest only constitutes 10% of the available hammock habitat and much of that habitat is in small patches and fragmented. Instead of nesting in once prevalent stick-nests (Chapter II), KLWRs have selected garbage and piles of rock over other substrates for making their nests.

The limiting factors on the KLWR population are still unknown and many hypotheses about them are still untested. One possible source of the KLWR population decline, the raccoon roundworm (*Baylisascaris procyonis*), a parasite that negatively affected the Alleghany woodrat (*N. magister*) population (McGowan1993, LoGiudice 2001, LoGiudice 2003), appears to be absent on Key Largo, Florida. It therefore is not hindering or limiting the KLWR population.

KLWR males had larger ranges and were less socially tolerant of one another than females. I believe KLWR ranges differed by sex during the spring and summer because of breeding activity.

I still do not understand all of the factors that have pushed the KLWR to the edge of extinction, yet from past trends in the population and future projections I do know that inaction is not an option. With that understanding, I strongly recommend:
(1) the creation of large patches (>20 ha) of young habitat in north Key Largo, and research to determine their effect on KLWR movements and demographics, (2) restoring old roads that bisect young forest and the placement of nesting materials throughout young habitat, areas of known KLWR use, and areas designated for introductions of KLWRs, (3) a large scale captive-breeding program capable of producing up to 20 KLWR females annually for reintroduction (this program should include intensive research on KLWR behavior, diet and reproductive rates) (4) continued research on wild and introduced KLWRs to determine limiting factors on the population including toxicology, predation, and disease, and (5) the creation of an outreach and educational program to promote and increase an understanding of the KLWR's dire situation, and to help build consensus and support for future management action aimed at recovering the KLWR.

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