POPULATION MODELING IN CONSERVATION PLANNING OF THE LOWER KEYS MARSH RABBIT

A Thesis

by

DAVID HOWARD LAFEVER

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

August 2006

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,	Roel R. Lopez
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ABSTRACT

Population Modeling in Conservation Planning of the Lower Keys Marsh Rabbit.

(August 2006)

David Howard LaFever, B. S., Virginia Polytechnic Institute and State University

Chair of Advisory Committee: Dr. Roel R. Lopez

Rapid development and urbanization of the Lower Florida Keys in the last 30 years has fragmented the habitat of the Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*) and threatened it with extinction. Current threats exist at multiple spatiotemporal scales and include threats due to development, invasive species, and global climate change. On Boca Chica Key, the Lower Keys marsh rabbit (LKMR) exists as a metapopulation on Naval Air Station-Key West (NASKW). I conducted a population viability analysis to determine the metapopulation's risk of extinction under multiple management scenarios by developing a spatially-explicit, stage-structured, stochastic matrix model using the programs RAMAS Metapop and ArcGIS. These management scenarios include clearance of airfield vegetation, habitat conversion, and control of feral cats as an invasive species. Model results provided the Navy with relative risk estimates under these different scenarios. Airfield clearance with habitat conversion increased extinction risk, but when coupled with feral cat control, risk was decreased.

Because of the potential of sea-level rise due to human-induced global climate change, and its projected impact on the biodiversity of the Florida Keys, I estimated the impacts of rising sea levels on LKMR across its geographic distribution under scenarios of no, low (0.3m), medium (0.6m), and high (0.9m) sea-level rise. I also investigated impacts due to 2 treatments (allowing vegetation to migrate upslope and not allowing migration), and 2 land-use planning decisions (protection and abandonment of human-dominated areas). Not surprisingly, under both treatments and both land-use planning decisions, I found a general trend of decreasing total potential LKMR habitat with increasing sea-level rise. Not allowing migration and protecting human-dominated areas both tended to decrease potential LKMR habitat as compared with allowing migration and abandoning human-dominated areas. In conclusion, conservation strategies at multiple scales need to be implemented in order to reduce threats to LKMR, such as development, invasive species, and global climate change.

DEDICATION

To my beautiful wife, Kristin E. LaFever

who taught me how to live and how to love

ACKNOWLEDGEMENTS

First, I want to thank my advisor, Dr. Roel Lopez, for his mentorship, guidance, wisdom, and most of all his sense-of-humor. Next, I want to thank my committee members: Dr. Nova Silvy for letting me crash in his house in the Keys and for worrying about us when we came back late from fishing, and Dr. Rusty Feagin for guidance and conversations on the sea-level rise portion of this thesis. I also want to thank Drs. Slack, Wu, and Peterson (MJP) for their wisdom in and out of the classroom. I thank Elizabeth Forys, Craig Faulhaber, and Neil Perry for the use of their data and constructive criticisms on manuscripts. The Department of Wildlife and Fisheries Sciences provided a lot of support and assistance during my time here, and I want to thank the office staff in particular for all their help. Many thanks to Amy Snelgrove for all of her patience with me and my GIS issues. I also want to thank the United States Navy, Southern Division, Naval Facilities Engineering Command, in particular Rodney Fleming and Ed Barham for logistical and financial support.

I want to thank all the friends and fiends in College Station for all the joy, laughter, and good times: Kevin Baker, Eric Branton and Emily Hollister, Meg Byerly, Reagan Errera, Tom "Doppler Lieberman" Dixon, Paige Hill and Jason Schmidt (and Gem), Christa Iocono and Ninja, Anna Munoz and Karlos Sachs (and the 3 who shall not be named), Michael Parkes, Sir Reginald James Pinkerton Esq., "Robo" Robert Powell (and Scouter Marie and Magnolia Pearl), the Fontaine Family (Lance, Eve, and Kaya), the Krawbutz Family (Peter, Rachel, Luka Verde, and Samantha Bleu), the Lee Family (Daniel, Stephanie, Jack, Baxter, Rizzo, and the spiny softshell), the Lyons Family

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CHAPTER I

INTRODUCTION

BACKGROUND

The purpose of this introductory chapter is to provide the reader with general background information on the Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*, LKMR). The chapter begins with a description of the LKMR, its distribution, a description of the study site, conservation issues and current status. It concludes with a review of the research objectives for this thesis.

The LKMR is one of 3 subspecies of *Sylvilagus palustris* whose distribution is limited to Florida's Lower Keys. The other 2 subspecies, *Sylvilagus palustris palustris* and *Sylvilagus palustris paludicola*, are distributed from southern Virginia to Georgia, and the Florida mainland and upper Keys, respectively (Layne, 1974; Lazell, 1984). The Lower Keys form the end of a string of islands that extend in a southwesterly arc from the southern tip of peninsular Florida (Fig. 1.1) and are separated from the upper keys by the approximately 11 km long Moser Channel. Geographic isolation by this channel is thought to have provided the necessary separation and isolation for the differentiation of the LKMR (Lazell, 1984).

The Florida Keys (Fig. 1.1), which border the southeastern tip of the Florida peninsula, are low-lying islands composed of Pleistocene limestone (Forys, 1995). They form an arcuate chain extending from Soldier Key

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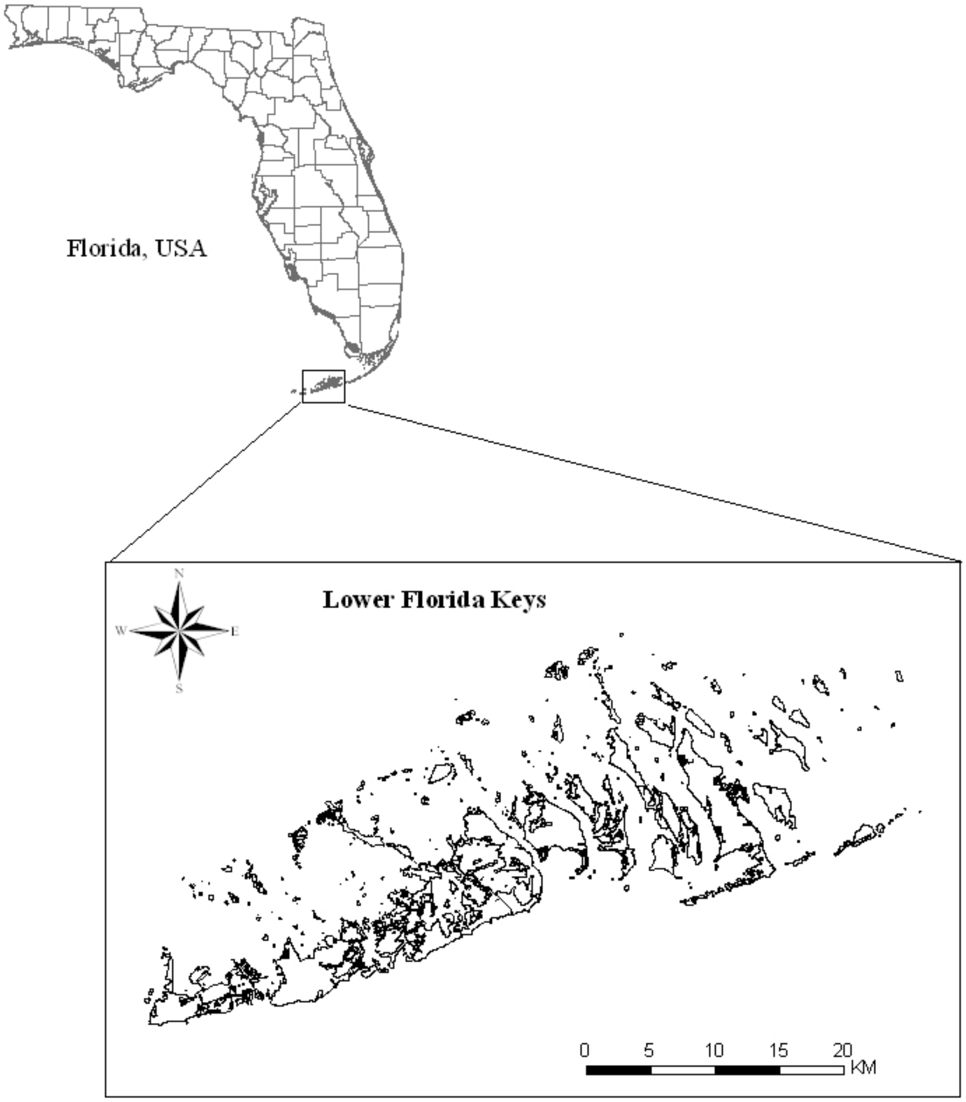


Fig. 1.1. The Lower Florida Keys, Florida, USA.

(15 km southeast of Miami) south and west to Key West, a distance of 240 km. The Keys are divided into the Upper Keys, from Bahia Honda northward, and the Lower Keys, from Big Pine Key to Key West. The Lower Keys form the terminal portion of this archipelago, and exhibit a subtropical climate due to the Gulf Stream and other maritime influences (Chen and Gerber, 1990; Forys and Humphrey, 1999*b*). There are distinct wet and dry seasons, with the dry season (November through April) contributing less than one third of annual precipitation (Forys and Humphrey 1999*a*). Although elevation in the Lower Keys rarely exceeds 2 m, small variations in elevation result in distinct vegetation associations. With increasing elevation, the vegetation community transitions from mangrove swamps to saltmarsh/buttonwood transition zones to upland hardwoods and pine hammocks (McGarry MacAulay et al., 1994; Faulhaber, 2003; Fig. 1.2). LKMRs occupy saltmarsh/buttonwood transition zones dominated by salt-tolerant grasses and shrubs including seashore dropseed (*Sporobolus virginicus*), sea daisy (*Borrichia frutescens*), gulf cord grass (*Spartina spartinae*), marsh hay cord grass (*S. patens*), and saltmarsh fringe-rush (*Fimbristylis castanea*), often with an open canopy of buttonwood trees (*Conocarpus erectus*) (Faulhaber, 2003; Forys and Humphrey, 1999*a*). This community occurs from approximately 0.5–1.0 m above sea level (Lopez, 2001), is subject to tidal flooding, and occurs between the mangrove community and the upland hardwoods or pine hammocks (Forys and Humphrey, 1999*a*; Fig. 1.2). The LKMR also occupies freshwater marshes and were known historically to occupy coastal beach berms (Faulhaber, 2003).

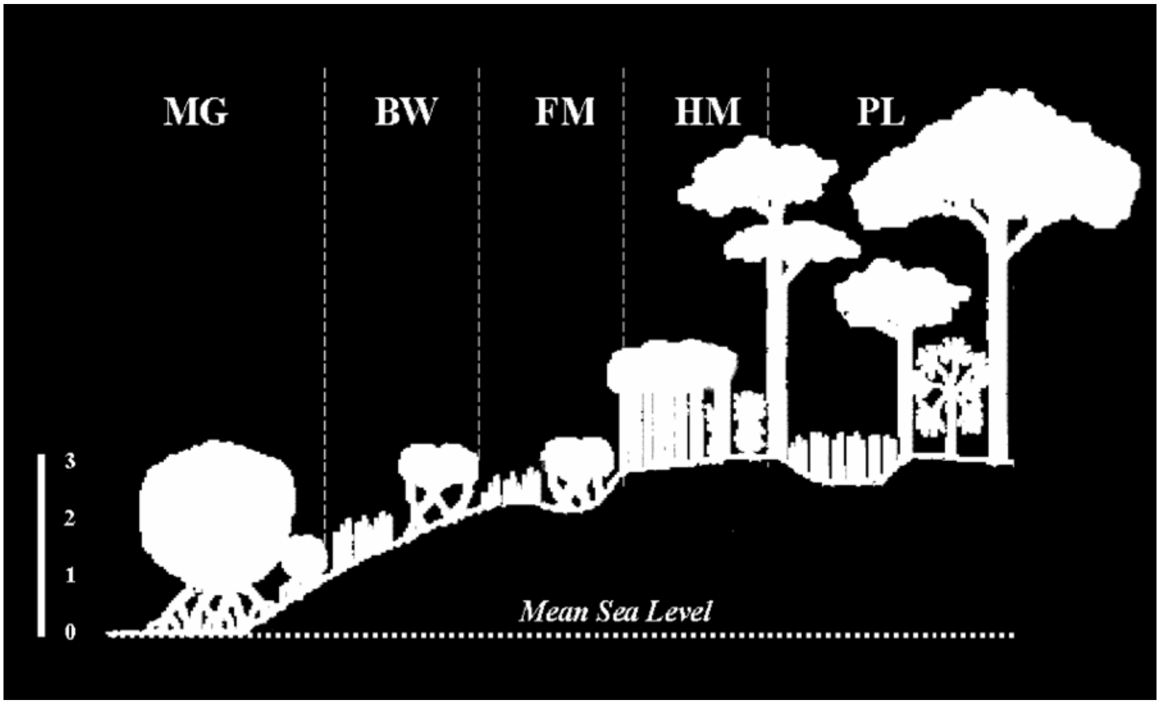


Fig. 1.2. Vegetation types of the Lower Keys of Florida, USA. MG = mangroves, BW = buttonwood/saltmarsh, FM = freshwater marsh, HM = hammock, PL = pineland in relation to elevation (meters) above mean sea level.

The LKMR was listed as a federally endangered species by the United States Fish and Wildlife Service (USFWS) in 1990 (USFWS, 1990). Historically, the LKMR occurred on all the Lower Keys surveyed (dePourtales, 1877), but rapid development from the 1970s to the present has resulted in a decline of LKMR populations (Forys and Humphrey, 1999*a*). Over the last 20 years, more than half of the suitable LKMR habitat in the Lower Keys has been lost due to human activities (USFWS, 1999). The USFWS (1999) cited habitat loss and fragmentation caused by development as the primary reasons for the subspecies' decline. Other potential threats to LKMRs include mortality caused by feral cats (*Felis catus*) and raccoons (*Procyon lotor*), and roads (Howe, 1988; Forys and Humphrey, 1996; USFWS, 1999). Due to alteration of habitat, salt marshes of the Lower Keys exist as highly fragmented mosaics of patches (Forys and Humphrey, 1999*b*), and the LKMR currently exists as three separate metapopulations; (1) Big Pine Key, (2) Saddlebunch/Lower Sugarloaf keys (hereafter, Saddlebunch Keys), and (3) Boca Chica Key (Forys and Humphrey, 1999*a*). A distribution survey conducted by Faulhaber (2003) found there to be 42 patches of habitat encompassing 284 ha on Big Pine Key, 50 patches encompassing 135 ha on Boca Chica (and neighboring East Rockland and Geiger keys), and 51 patches totaling 135 ha on the Saddlebunch Keys.

RESEARCH OBJECTIVES

The overall study objective was to develop population models that could be used to evaluate the impact of conservation planning on the LKMR. The information generated from these models will facilitate the management and conservation of this endangered species. Two chapters in this thesis address these objectives. The chapters are:

1. Population viability analysis for conservation planning
2. Sea-level rise and its impacts

A final chapter will discuss implications from research findings, and propose future conservation actions and directions. Chapters are independent papers, and a certain amount of repetition in material presented should be expected.

CHAPTER II

POPULATION VIABILITY ANALYSIS FOR CONSERVATION PLANNING

SYNOPSIS

Rapid development and urbanization of the Lower Florida Keys in the last 30 years has fragmented the Lower Keys marsh rabbit's (*Sylvilagus palustris hefneri*, LKMR) habitat and threatened it with extinction. On Boca Chica Key the LKMR exists as a metapopulation on the Naval Air Station-Key West (NASKW). I conducted a population viability analysis to determine the metapopulation's risk of extinction under multiple management scenarios. I developed a spatially-explicit, stage-structured, stochastic matrix model using the programs RAMAS Metapop and ArcGIS. Model parameters were estimated using pellet counting (2001–2002), radio tracking (1991–1992, $n = 53$ and 2001–2005 $n = 22$), and published literature. Model results provided the Navy with relative risk estimates under different management scenarios. The Navy has identified 2 alternative actions that would bring Boca Chica Airfield into compliance with required safety regulations. Alternative 1 would result in restoration of the original airfield clearance surface but includes no conservation measures for the LKMR. Alternative 2 incorporates conservation measures to minimize impact to LKMR while achieving compliance with airfield safety regulations. A baseline model is included for comparison purposes. Both alternatives increased the extinction risk (probability of extinction) from a baseline of 0.499 to 0.713 and 0.90 for Alternatives 2 and 1, respectively. Although airfield clearance with habitat conversion (Alternative 2)

increased extinction risk, habitat conversion with feral cat control was an effective strategy to decrease this risk. My model is currently being used to inform management decisions to minimize the impact of vegetation clearance on the LKMR.

INTRODUCTION

Population models that fully integrate physical, biological, and human systems are essential for evaluating risks associated with accommodating changes in natural habitats (Grant and Thompson, 1997; Liu, 2001). Wildlife conservationists now face the challenge of predicting how expansion of human-influenced systems will impact endangered species viability. To accomplish this task, researchers must integrate models simulating extinction risk with those simulating development. Population Viability Analysis (PVA) models are based on demographic and habitat data, incorporate uncertainties using sensitivity analyses based on ranges of parameters, and provide outputs or predictions that are relevant to conservation goals (Boyce, 1992; Akçakaya and Sjogren-Gulve, 2000). Despite the widespread application of PVA, caution needs to be exercised when constructing and interpreting a PVA model. This is especially important when it involves an endangered species, because data requirements for a PVA can be large, and are often difficult to obtain when little is known about an endangered species (Beissinger and Westphal, 1998).

Despite these limitations, PVA can be a powerful conservation planning tool, particularly in the context of multiple management options. PVA should be used to make relative predictions of extinction risk over short time frames (e.g., 10, 20 or 50 year time frames) (Noon and McKelvey, 1996; Beissinger and Westphal, 1998; Akçakaya and Sjogren-Gulve, 2000; Reed et al., 2002), and to rank the impacts of various management options on endangered species (Lindenmayer and Possingham, 1996; Beissinger and Westphal, 1998). Because of the uncertainty associated with parameter estimates, sensitivity analysis is an important part of conducting a population viability analysis (Parysow and Tazik, 2002; McCleery et al., 2005). Sensitivity analysis identifies important parameters and assumptions of the model, and can be directed towards identifying the parameters which would decrease uncertainty in the model if they were known with higher precision (Akçakaya and Sjogren-Gulve, 2000).

This study sought to apply population viability analysis to conservation planning for the LKMR. The LKMR was listed as a federally endangered species by the United States Fish and Wildlife Service (USFWS) in 1990 (USFWS, 1990). Historically, the LKMR occurred on all the Lower Keys surveyed, but rapid development from the 1970s to the present has resulted in a decline of LKMR populations (Forys and Humphrey, 1999*a*). Over the last 20 years more than half of the suitable LKMR habitat in the Lower Keys has been lost due to human activities (USFWS, 1999). The USFWS (1999) cited habitat loss and fragmentation caused by development as the primary reasons for the subspecies' decline. Other potential threats to LKMRs include mortality caused by feral cats (*Felis catus*), and raccoons (*Procyon lotor*) (Howe, 1988; Forys and Humphrey, 1996).

Background

The metapopulation of LKMR on Boca Chica Key (Fig. 2.1) likely will be impacted by proposed habitat modifications on Boca Chica Airfield, the primary airfield of the United States Navy's NASKW. Currently, Boca Chica Airfield is not in compliance with required safety regulations set forth in United States Department of Defense, Naval Facilities, and Federal Aviation regulations. Compliance requires removal of woody vegetation within a designated airfield clearance zone and the restoration of drainage canals that have become clogged with vegetation. Removal of vegetation on Boca Chica Airfield could harm the LKMR through modification of habitat and direct mortality from construction (Faulhaber 2005). Without the proposed modifications, Forys and Humphrey (1999*a*) predicted 11 years until extinction with a probability of extinction of 1.00 for this metapopulation. Thus, any further negative impacts are undesirable.

The objectives of my study were to (1) develop a spatially-explicit and stochastic, stage-structured matrix model of the LKMR on Boca Chica Key, Florida, USA, (2) determine the impact of 3 different airfield clearance scenarios on population viability, (3) determine the impact of conservation strategies (e.g., feral cat control) on viability, (4) conduct a sensitivity analysis of model parameters to guide future research and management, and (5) provide Navy biologists a model for evaluating management actions and recovery strategies for the LKMR on Boca Chica Key.

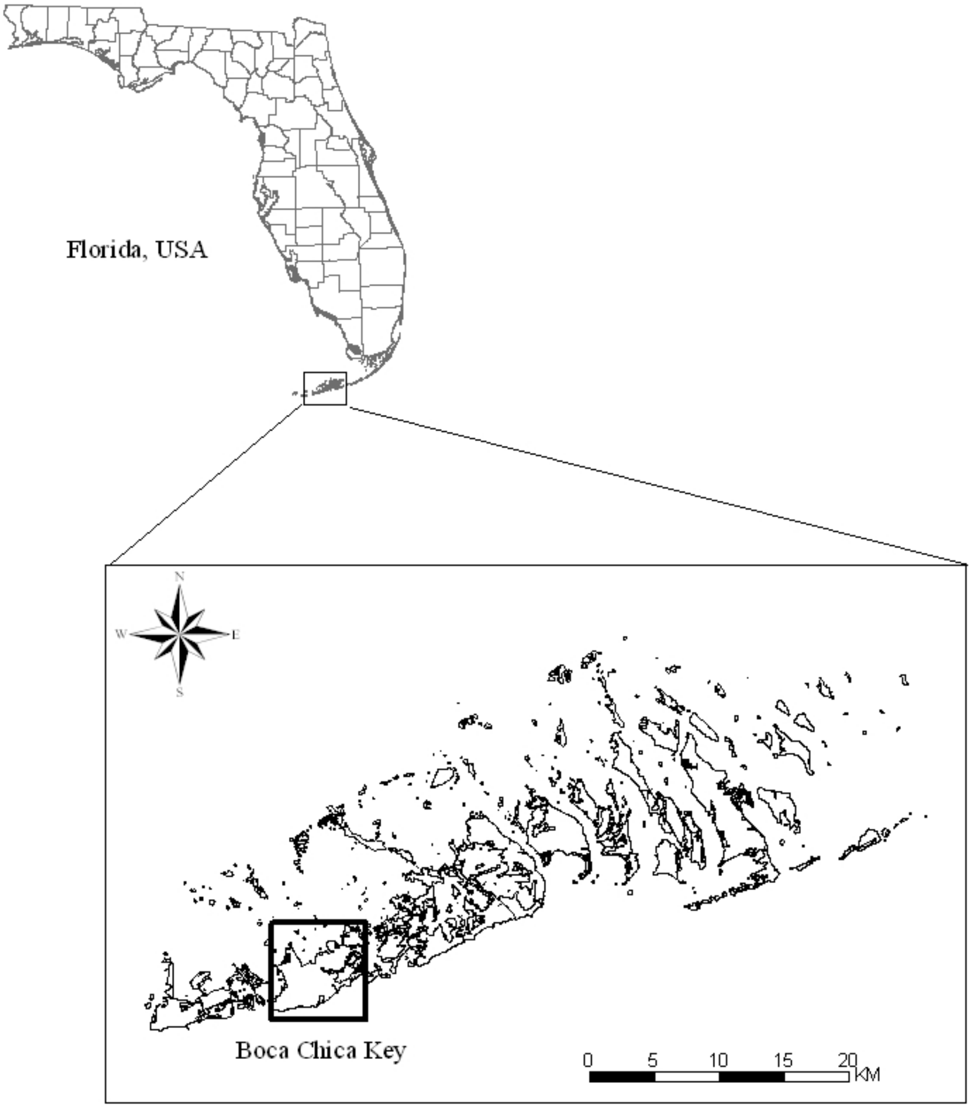


Fig. 2.1. The island of Boca Chica Key located in the Lower Florida Keys, Florida, USA.

STUDY AREA

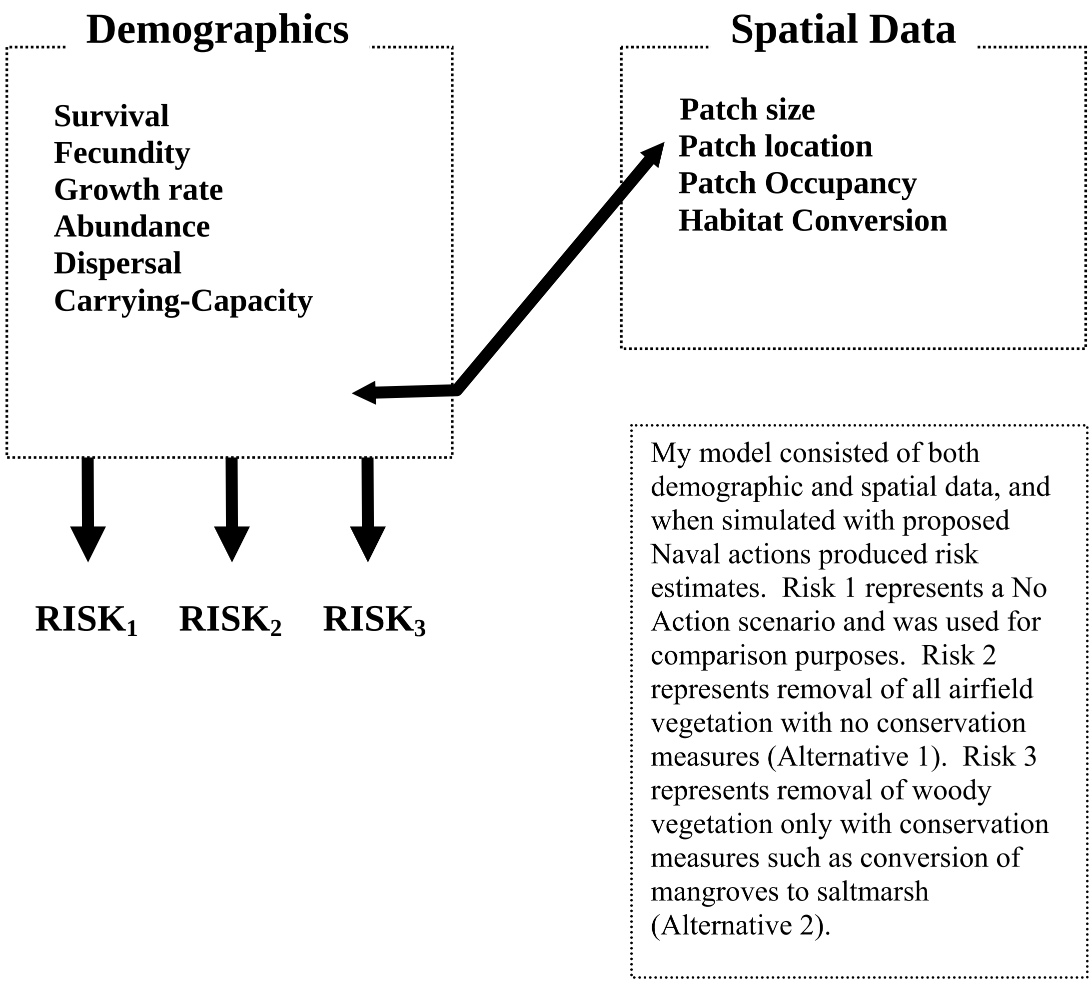
The Lower Keys form the terminal portion of an archipelago of islands extending south and west from the mainland of Florida, USA, (Fig. 2.1), and exhibit a subtropical climate due to the Gulf Stream and other maritime influences (Chen and Gerber, 1990; Forys and Humphrey, 1999*b*). There are distinct wet and dry seasons, with the dry season (November through April) contributing less than one third of annual precipitation (Forys and Humphrey, 1999*a*). Although elevation rarely exceeds 2 m, small variations in elevation result in distinct vegetation types. With increasing elevation the vegetation community transitions from mangrove swamps to saltmarsh/buttonwood transition zones to upland hardwoods and pine hammocks (McGarry MacAulay et al., 1994). In general, LKMRs occupy saltmarsh/buttonwood transition zones dominated by salt-tolerant grasses and shrubs including seashore dropseed (*Sporobolus virginicus*), sea daisy (*Borrichia frutescens*), gulf cord grass (*Spartina spartinae*), marsh hay cord grass (*Spartina patens*), and saltmarsh fringe-rush (*Fimbristylis castanea*), often with an open canopy of buttonwood trees (*Conocarpus erectus*). This community occurs from approximately 1–3 m above sea level, is subject to tidal flooding, and occurs between the mangrove community and the upland hardwoods or pine hammocks (Forys and Humphrey, 1999*a*). The LKMR also occupies freshwater marshes and were known historically to occupy coastal beach berms (Faulhaber, 2003). Due to alteration of habitat, saltmarshes of the Lower Keys exist as highly fragmented mosaics of patches (Forys and Humphrey, 1999*b*), and the LKMR now exists as 3 separate metapopulations on Big Pine, the Saddlebunch/Lower Sugarloaf, and Boca Chica keys (Forys and

Humphrey, 1999*a*). A distribution survey conducted by Faulhaber (2003) found there to be 42 occupied patches, encompassing 135 ha of habitat on Boca Chica, and neighboring Geiger and East Rockland keys.

METHODS

Model Overview

RAMAS-Metapop is a valid and sufficiently precise modeling program for population viability analysis (Brook et al., 2000), and was used to construct a demographic and spatial model of the LKMR metapopulation on Boca Chica Key (Fig. 2.2). My model consisted of 3 demographic stages: juveniles, first year adults, and adults 2 year or older. Both demographic and environmental stochasticity were incorporated into the model. Demographic stochasticity was modeled by sampling from a binomial distribution and a Poisson distribution, for the number of survivors and number of offspring, respectively (Akçakaya, 1991). Environmental stochasticity was modeled by randomly sampling mean survival and fecundity from the stage matrix and standard deviations from a “standard deviation matrix” (Akçakaya, 1991). Ceiling type density-dependence was incorporated by including the carrying capacity of each subpopulation in the model. Estimates of carrying capacity were based on the area of a rabbit patch and the average core area used by rabbits, because it has been shown that same-gender ranges show little overlap (Forys and Humphrey, 1996). Because I modeled females only, carrying capacity is based on the number of females that can fit in a patch.



My model consisted of both demographic and spatial data, and when simulated with proposed Naval actions produced risk estimates. Risk 1 represents a No Action scenario and was used for comparison purposes. Risk 2 represents removal of all airfield vegetation with no conservation measures (Alternative 1). Risk 3 represents removal of woody vegetation only with conservation measures such as conversion of mangroves to saltmarsh (Alternative 2).

Fig. 2.2. Conceptual diagram of the Lower Keys marsh rabbit population viability model on Boca Chica Key, Florida, USA.

Patch carrying capacities were summed to give a subpopulation carrying capacity which was then entered into the model.

Spatial information was incorporated into the PVA model by mapping out the impacts from the airfield clearance scenarios in ArcGIS (version 8.3, Environmental Systems Research Institute, Redlands, California, USA), and integrating these impacts into RAMAS Metapop (Applied Biomathematics, Setauket, New York, USA). Dispersal was based on a distance-function matrix, with dispersal between patches decreasing with increasing distance.

Model Parameterization

Baseline Scenario

Model parameters (Table 2.1) were estimated using pellet counts (2001–2002), radio tracking (1991–1992, $n = 53$ and 2001–2005, $n = 22$ rabbits), and published and unpublished literature (Forys, 1995; Forys and Humphrey, 1999*a*; Faulhaber, 2005; Faulhaber et al., *in press*). The baseline scenario represents a "no action" scenario and was used to compare relative changes in viability due to the other scenarios.

Alternative 1 Scenario

Alternative 1 was parameterized as above, but with simulated impacts from the airfield clearance project. Under this scenario, all vegetation is removed within the airfield clearance zone. Impacts of this action were estimated using ArcGIS, and integrated with RAMAS Metapop. This scenario contains no conservation measures for the LKMR.

Alternative 2 Scenario

Alternative 2 was parameterized as Alternative 1, but with woody vegetation only being removed within the airfield clearance zone and herbaceous vegetation was left standing. Also, under this scenario mangroves within rabbit patches were converted to saltmarsh as a conservation measure. The impact of these actions was estimated using ArcGIS, and integrated with RAMAS Metapop.

Table 2.1. Baseline model parameter estimations and data sources used in a Population Viability Analysis of the Lower Keys marsh rabbit on Boca Chica Key, Florida, USA.

Parameter	**Estimate**	**Source**
Fecundity		
Adult 1	0.57	Forys, 1995
Adult 2+	0.09	
Survival		
Juvenile	0.52	Forys, 1995; Forys and Humphrey, 1999*a*; Faulhaber et al., 2005
Adult 1	0.52	
Adult 2+	0.25	
Initial Abundance	specific to each subpopulation	Faulhaber, 2005
Average Dispersal		
Juvenile	300 m	Forys, 1995
Maximum Dispersal		
Juvenile	3000 m	Forys, 1995
Carrying Capacity	specific to each subpopulation	Forys and Humphrey, 1996

Feral Cat Control Scenarios

Forys (1995) found that 53% of LKMR mortality was due to feral cats. The 3 models above were combined with 2 different feral cat control scenarios. I simulated scenarios where 50% and 75% of LKMR mortality due to feral cats was reduced, respectively. Increases in survival (Table 2.2) due to these scenarios were calculated for each demographic stage, and re-entered into the model.

Table 2.2. Annual survival estimates used in Population Viability Analysis for the Lower Keys marsh rabbit by age-class and level of feral cat control (% population reduction) on Boca Chica Key, Florida, USA, 2005.

	0%	**50%**	**75%**
Juvenile	0.520	0.647	0.710
Adult 1	0.520	0.647	0.710
Adult 2	0.255	0.424	0.551

Sensitivity Analysis

I used RAMAS Metapop to conduct a sensitivity analysis of parameter estimates for this PVA. Sensitivity of model parameters was investigated by varying each parameter by ±25% of the baseline estimate while holding all other parameters constant (Akçakaya, 2000). Terminal quasi-extinction risk was used as a measure of the effect of each parameter estimate on viability of the LKMR metapopulation on Boca Chica Key.

Absolute values of low estimates were subtracted from absolute values of high estimates for this analysis.

Model Use

The above scenarios were evaluated in terms of LKMR viability by running 1,000 iterations of the model over 10 years. A short time frame has been suggested as most appropriate for endangered species population viability analyses (Beissinger and Westphal, 1998). I used 2 criteria to assess viability: terminal quasi-extinction risk, and median time to extinction. Terminal quasi-extinction risk is the probability of the metapopulation falling below a threshold of 10 individuals within 10 years, and median time to extinction is measured in years. Quasi-extinction was used to account for potential Allee effects (Allee, 1931; Groom, 1998; Stephens et al., 1999; Lacy, 2000).

RESULTS

My model indicates the finite rate of increase (λ) is 0.6049, and that 22 out of 25 subpopulations are below carrying capacity. The baseline scenario resulted in a terminal quasi-extinction risk of 0.584 (Fig. 2.3) and a median time to quasi-extinction of 5.1 years (Figure 4). Quasi-extinction risk for Alternative 1 was 0.905 (Fig. 2.3), while median time to quasi-extinction was 2.7 years (Fig. 2.4). Quasi-extinction risk for Alternative 2 was 0.633 (Fig. 2.3), and median time to quasi-extinction was 4.7 years (Fig. 2.4).

The finite rate of increase (λ) increased from a baseline of 0.6049 to 0.7156 and 0.7777 with 50% and 75% cat control, respectively. Baseline quasi-extinction risk decreased to 0.103 and 0.020 (Fig. 2.3), and median time to quasi-extinction increased to 7.6 and 9.8 years (Fig. 2.4) with 50% and 75% cat control, respectively. Both alternatives coupled with cat control decreased the quasi-extinction risk (Fig. 2.3) and increased median time to extinction (Fig. 2.4). Quasi-extinction risk was virtually eliminated under both the baseline and Alternative 2 scenarios with 75% cat control (Fig. 2.3). The 3 most sensitive parameters for terminal extinction risk were initial abundance, juvenile survivorship, and fecundity of adult 1 stage (Fig. 2.5).

DISCUSSION

Population Viability

Overall, the outlook for the LKMR metapopulation on Boca Chica Key, Florida, is dismal without future conservation actions. Under all 3 scenarios the Boca Chica Key metapopulation of the LKMR is at high risk of extinction, with the model predicting extinction within 10 years (Fig. 2.3 and 2.4). Even with no action (i.e., baseline scenario) extinction is predicted in 10 years. This indicates that conservation action is needed if this metapopulation is to persist into the future.

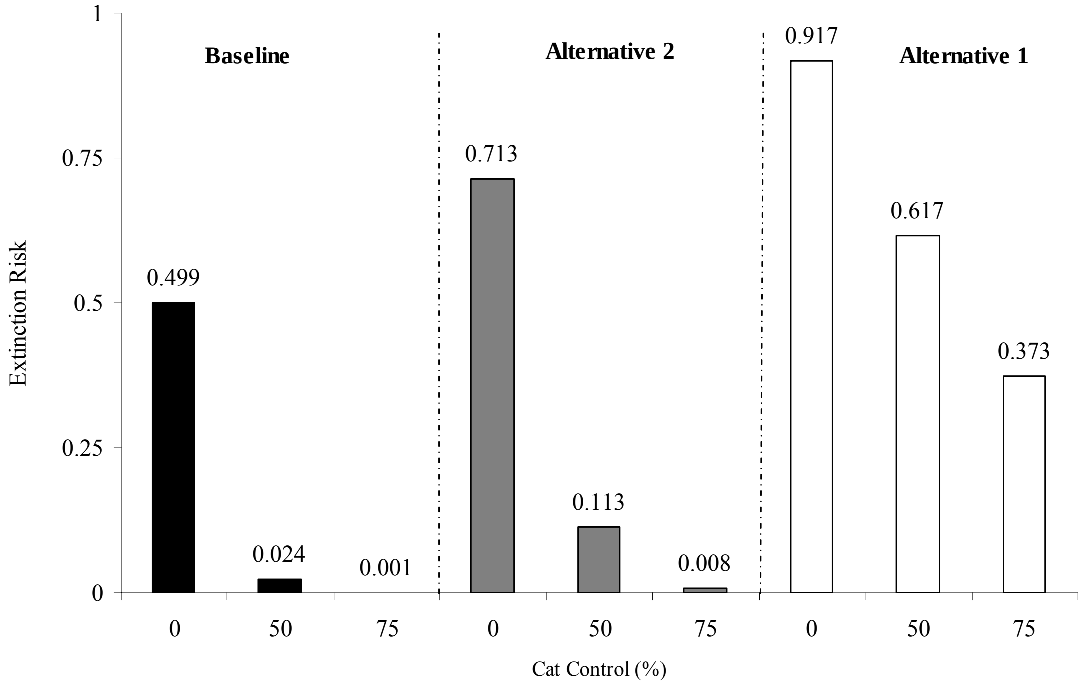


Fig. 2.3. Terminal extinction risk (probability of quasi-extinction in 10 years) for the Lower Keys marsh rabbit on Boca Chica Key, Florida, USA under several management scenarios. Baseline is the "no action" alternative, Alternative 2 is airfield vegetation clearance plus habitat improvement, and Alternative 1 is airfield vegetation clearance with no habitat improvement. Cat control is the percent reduction in Lower Keys marsh rabbit mortality due to cats.

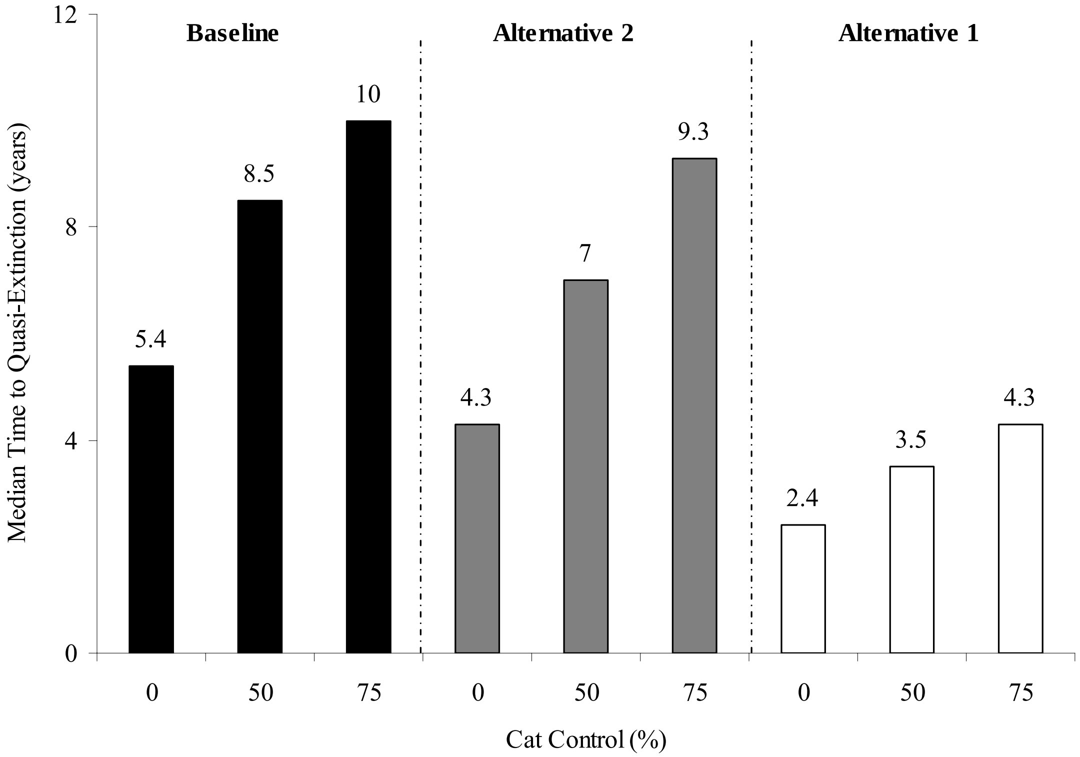


Fig. 2.4. Median time to quasi-extinction (in years) for the Lower Keys marsh rabbit on Boca Chica Key, Florida, USA under several management scenarios. Baseline is the "no action" alternative, Alternative 2 is removal of woody airfield vegetation plus habitat improvement, and Alternative 1 is removal of all airfield vegetation with no habitat improvement. Cat control is the percent reduction in Lower Keys marsh rabbit mortality due to cats.

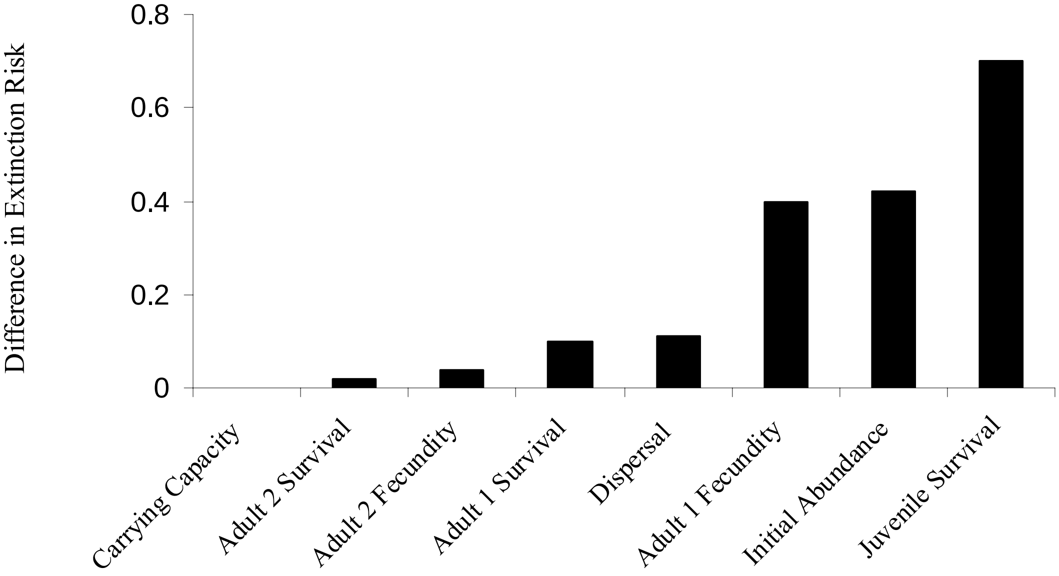


Fig. 2.5. Sensitivity analysis (differences in terminal extinction risk between high and low parameter values) of model results for the Lower Keys marsh rabbit on Boca Chica Key, Florida, USA. Parameter values were varied ±25% from baseline estimate.

Sensitivity Analysis

The analysis indicates that initial abundance, juvenile survivorship, and adult 1 fecundity (1-2 year old adults) are the most sensitive parameter estimates in this model. This suggests that model uncertainty can be improved if better estimates for these parameters are obtained. Within the bounds of limited resources for research, I suggest field efforts focus on initial abundance estimates for rabbit subpopulations on Boca Chica Key. In order to improve estimates of survivorship and fecundity, radio-telemetry would be necessary, but radio-telemetry is a relatively invasive and labor intensive technique. Initial abundance estimates, however, can be obtained by conducting fecal pellet count surveys (Wood, 1988; Forys and Humphrey, 1997; Prugh and Krebs, 2004), which does not necessitate capturing rabbits. This method has been show to be an efficient method for species that are difficult to trap, such as the LKMR (Forys and Humphrey, 1997; Prugh and Krebs, 2004). An updated estimate of rabbit abundance is needed to improve model accuracy and to help with conservation planning for the LKMR.

Conservation Implications

Overall, the population viability for the LKMR population on Boca Chica Key, Florida is dismal without future conservation actions. Under all 3 scenarios the Boca Chica Key metapopulation of the LKMR is at high risk of extinction with the model predicting extinction within 10 years (Fig. 2.3 and 2.4). Even with no action (i.e., baseline scenario) extinction is predicted in 10 years. This indicates that conservation measures need to be implemented if this metapopulation is to persist into the future. With a finite rate of increase below 1.0, this metapopulation is declining. This combined with the majority of subpopulations being below carrying capacity (i.e., 22 of 25 are below carrying capacity), and the simulation results provides evidence that cat predation is a major factor in the decline of this endangered species. Modeled effects of conservation measures such as cat control provide hope for the persistence of this metapopulation. All 3 scenarios with cat control improved the persistence time and decreased the extinction risk. These results reinforce those found by Forys and

Humphrey (1999*a*). They found an extinction risk of 1.00 in 11 years under a baseline scenario, but found an extinction risk of 0.46 with 33 years to extinction when all feral cat mortality was removed. Feral cats have been found to be the cause of biodiversity extinction on islands throughout the world (Whittaker, 1998). Subsequent eradication programs have been successful on many islands, particularly those <5 km^2, and uninhabited by people (Nogales et al., 2004). Although total eradication of cats from Boca Chica Key is unlikely due to social constraints, a reduction of 50–75% should greatly increase the viability of the LKMR. Control of feral cat populations is imperative if the LKMR is to persist into the future, but a concomitant environmental education program should be implemented in order to alleviate public displeasure in such programs.

Model results indicate that predator control may be a more important factor than habitat conservation for Lower Key marsh rabbit recovery on Boca Chica Key. I found 22 out of 25 subpopulations are currently under carrying capacity, most likely due to predation pressure. If current habitat patches are not saturated with individuals, increasing habitat conservation will result in little or no positive impact. Conservation of habitat is often cited as one of the most important part of conservation planning (Noss, 2003; Guenette and Villard, 2005; Peralvo et al., 2005). Although I do not dispute the importance of habitat conservation, the simulation results suggest that predation pressure may be a more immediate threat for some species. I suggest that demographic features of a population (e.g., survival and fecundity) should also be considered when planning for conservation or the recovery of an endangered species.

Simply protecting habitat and habitat corridors may not be enough for the conservation of some species.

CHAPTER III

MODELING THE IMPACTS OF SEA-LEVEL RISE

SYNOPSIS

Human induced global climate change presents a unique and difficult challenge to the conservation of biodiversity. Despite increasing attention on global climate change, few studies have assessed the projected impacts of sea-level rise to threatened and endangered species. Therefore, I estimated the impacts of rising sea levels on the endangered Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*; LKMR) across its geographic distribution under scenarios of no, low (0.3m), medium (0.6m), and high (0.9m) sea-level rise. I also investigated the impacts of allowing vegetation to migrate upslope and not allowing migration, and 2 land-use planning decisions (protection and abandonment of human-dominated areas). Not surprisingly, under all simulations I found a general trend of decreasing total potential LKMR habitat with increasing sea-level rise. Not allowing migration and protecting human-dominated areas both tended to decrease potential LKMR habitat as compared with allowing migration and abandoning human-dominated areas. In conclusion, conservation strategies at multiple scales need to be implemented in order to reduce the impact of global climate change on biodiversity and endangered species. At the regional level, managers must consider land-use planning needs that take into account the needs of both humans and biodiversity. Lastly, at the local scale those agencies that are in charge of endangered species conservation and ecosystem management need to rethink static approaches to conservation or else stand by and watch ecosystems degrade and species go extinct. The can be

accomplished by bioclimatic reserve systems where climatically under-represented areas are included in conservation planning along with the standard concerns of threat, opportunity, connectivity, and viability.

INTRODUCTION

Human induced global climate change presents a unique and difficult challenge to the conservation of biodiversity. Global mean surface temperatures have increased 0.6° C since the late 19th century (Hughes, 2000) and an estimated 41% of wild species have responded to recent climate change with 74–91% of these species responding in accordance with climate change predictions (Parmesan and Yohe, 2003). Observed biological responses include range expansion (Parmesan, 1996; Parmesan et al., 1999; Thomas and Lennon, 1999), elevation shifts (Grabherr et al., 1994; Pounds et al., 1999), and changing disease dynamics (Pounds et al., 2006).

Sea-level rise, due mainly to oceanic thermal expansion, undoubtedly will have many impacts on small islands and coastal lowlands including increased likelihood of coastal flooding, salinization of freshwater wetlands and water tables, and coastal land loss (Intergovernmental Panel on Climate Change (IPCC), 2001; Fish et al., 2005). Titus and Richman (2001) mapped out coastal areas vulnerable to sea-level rise (i.e., those lying below 1.5 m in elevation) along the United States Atlantic and Gulf coasts and found approximately 58,000 km^2 of land lying below 1.5 m, which is within some estimates of sea-level rise by 2100. These estimates include an increase of 0.31–1.50 m (Daniels et al., 1993), 0.18–0.30 m (Meehl et al., 2005), and 0.09–0.88 m (IPCC, 2001) by the year 2100. Impacts on coastal wetlands (Lee et al., 1992; Moorhead and Brinson, 1995; Michener et al., 1997; Simas et al., 2001), coastal erosion (Feagin et al., 2005; Leatherman et al., 2000), and forests (Ross et al., 1994; Williams et al., 1999) have been assessed, but few studies have evaluated the impacts to threatened and endangered species (see Daniels et al, 1993; Shriver and Gibbs, 2004; Fish et al., 2005 for exceptions). Because of the lack of studies on endangered species, I assessed the impact of predicted sea-level rise on the endangered LKMR by estimating changes in its habitat due to projected sea level change.

The LKMR was listed as a federally endangered species by the United States Fish and Wildlife Service (USFWS) in 1990 (USFWS, 1990). Historically, the LKMR occurred on all the Lower Keys surveyed, but rapid development from the 1970s to the present has resulted in a decline of LKMR populations (Forys and Humphrey, 1999*a*). Over the last 20 years, more than half of the suitable LKMR habitat in the Lower Keys has been lost due to human activities (USFWS, 1999). The USFWS (1999) cited habitat loss and fragmentation caused by development as the primary reasons for the subspecies' decline. Other potential threats to LKMRs include mortality caused by feral cats (*Felis catus*), and raccoons (*Procyon lotor*) (Howe, 1988; Forys and Humphrey, 1996). Because its entire distribution occurs on low lying islands, it is a good candidate for investigating the impact of sea-level rise on an endangered species.

STUDY AREA

The Lower Keys form the terminal portion of an archipelago of islands extending south and west from the mainland of Florida, USA (Fig. 3.1) and exhibit a subtropical climate due to the Gulf Stream and other maritime influences (Chen and Gerber, 1990; Forys and Humphrey, 1999*b*). There are distinct wet and dry seasons, with the dry season (November through April) contributing less than one third of annual precipitation (Forys and Humphrey, 1999*a*). In general, LKMRs occupy saltmarsh/buttonwood transition zones dominated by salt-tolerant grasses and shrubs including seashore dropseed (*Sporobolus virginicus*), sea daisy (*Borrichia frutescens*), gulf cord grass (*Spartina spartinae*), marsh hay cord grass (*Spartina patens*), and saltmarsh fringe-rush (*Fimbristylis castanea*), often with an open canopy of buttonwood trees (*Conocarpus erectus*), but also occupy freshwater marshes (Faulhaber, 2003). Due to alteration of habitat, saltmarshes of the Lower Keys exist as highly fragmented mosaics of patches (Forys and Humphrey, 1999*b*), and the LKMR now exists as 3 separate metapopulations (Fig. 3.1) on (1) Big Pine, (2) Saddlebunch/Sugarloaf keys (hereafter, the Saddlebunch Keys), and (3) Boca Chica Key (Forys and Humphrey, 1999*a*). A distribution survey by Faulhaber (2003) found there to be 42 patches of habitat encompassing 284 ha on Big Pine Key; 50 patches, encompassing 135 ha on Boca Chica Key (and neighboring East Rockland and Geiger keys); and 51 patches totaling 135 ha on the Saddlebunch Keys. Current population estimates range from 100–300 individuals across the LKMR distribution (USFWS, 1999).

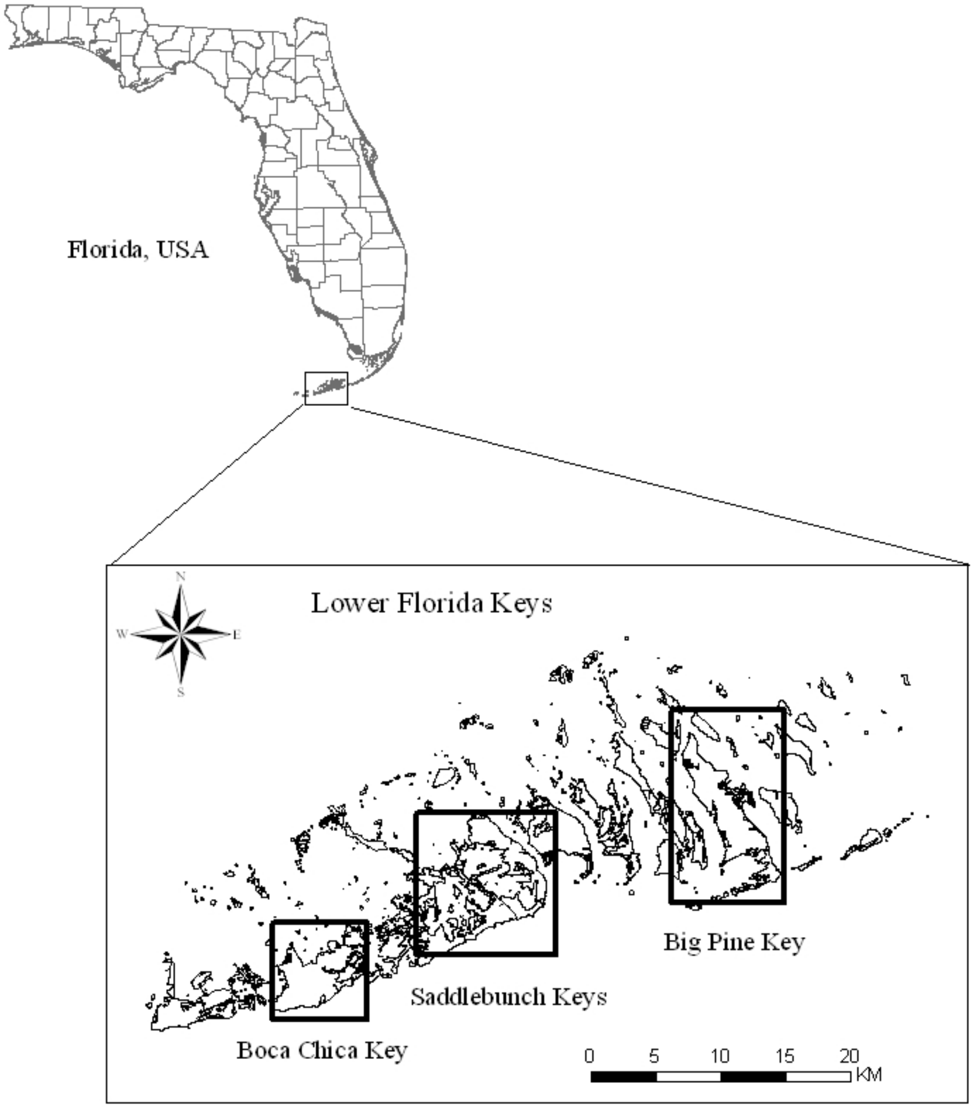


Fig. 3.1. Location of the Lower Florida Keys and the 3 metapopulations of the Lower Keys marsh rabbit: Big Pine Key, Saddlebunch Keys, and Boca Chica Key.

METHODS

I estimated the proportion of each vegetation type within each of 4 elevation categories in ArcGIS (v. 9.1, ESRI, Redlands, California) using a United States Geological Survey (USGS) digital elevation model (DEM; with 30 m horizontal and 0.3 m vertical resolution) and digitized vegetation map of the Lower Florida Keys (Faulhaber, 2003). The elevation categories were 0–0.3 m, 0.3–0.6 m, 0.6–0.9 m, and >0.9 m. I then simulated 3 sea-level rise scenarios: low (0.3 m), medium (0.6 m), and high (0.9 m) by 2100 (IPCC, 2001).

First, I assumed that plants would be able to migrate upslope (Moorhead and Brinson, 1995; Michener et al., 1997). I assumed that vegetation in the 0–0.3 m category migrated to the 0.3–0.6 m category, vegetation in the 0.3–0.6 m category migration to the 0.6–0.9 m category, and vegetation in the 0.6–0.9 m category migrated to the >0.9 m category. To do this, I took the proportion of each vegetation type each of these categories in the year 2000 and multiplied this by the total area in the next higher category for the 2000 dataset. For example, in the low rise scenario, all cells in the DEM with the value of 0–0.3 m were inundated with water, but the vegetation previously at this elevation migrated upslope to the cells with values of 0.3–0.6 m elevation.

My second approach assumed that no migration upslope occurred. This assumption is reasonable given that the rate of sea-level rise may be too great for plants to track upslope (Bush et al., 2004), and that abandonment of coastal lowlands is unlikely (Titus, 1991), thus, squeezing coastal plant communities between anthropogenic land barriers and rising sea levels (Feagin et al., 2005). Under this scenario when rising sea levels inundated an elevation category, we assumed that vegetation within that elevation was lost (i.e., no upslope migration occurred). Under low sea-level rise, for example, all cells in the DEM with values of 0–0.3 m are inundated with water and vegetation previously at this elevation is lost.

I simulated each of the 3 sea-level rise scenarios with and without migration and with two potential land-use planning decisions: protection of human dominated areas and abandonment of these areas (Titus, 1991). Human dominated areas include developed areas and roads. Protection was simulated by keeping human dominated areas constant throughout the simulations. Abandonment was simulated by allowing re-colonization of human dominated areas by vegetation at each elevation category in proportion to the area abandoned.

I calculated the total area (ha) of potential LKMR habitat under each simulation, and both the net and relative change between 2000 and 2100. This was done on each of the 3 main metapopulations: (1) Big Pine Key, (2) Boca Chica Key, (3) Saddlebunch Keys. Using the net change in potential LKMR habitat, I calculated the net change in the total number of LKMRs between 2000 and 2100 using current population estimates.

RESULTS

Big Pine Key

Overall, I estimated 1,172 ha of total potential LKMR habitat on Big Pine Key, Boca Chica Key, and the Saddlebunch Keys under current conditions with most (565 ha) occurring in the middle elevation category (Fig. 3.2). Big Pine Key has an estimated 294 ha of potential LKMR habitat with most occurring in the middle elevation category as well followed by the high, highest, and low elevation categories, respectively (Fig. 3.2). Under sea-level rise with migration of vegetation upslope, I found the amount of habitat decreased for both land-use planning decisions (i.e., protection and abandonment of developed areas) with a greater decrease occurring with protection (Fig. 3.3, graph 1a). With no migration of vegetation upslope and protection of developed areas, the amount of habitat decreased with increasing sea-level rise, while with abandonment it increased under low sea-level rise and then decreased under medium and high sea-level rise scenarios (Fig. 3.3, graph 1b). I also found more potential habitat with no migration under low sea-level rise, and less under medium and high as compared with no sea-level rise (Fig. 3.3, graph 1b). Lastly, under all sea-level rise scenarios abandonment of developed areas resulted in a greater amount of potential habitat than protection of developed areas (Fig. 3.3).

Boca Chica Key

Boca Chica Key has 209 ha of potential LKMR habitat under current conditions with most occurring in the low elevation category followed by the middle, highest, and high categories, respectively (Fig. 3.2). As with Big Pine Key, the amount of habitat decreased with increasing sea-level rise for both protection and abandonment with a greater decrease due to protection.

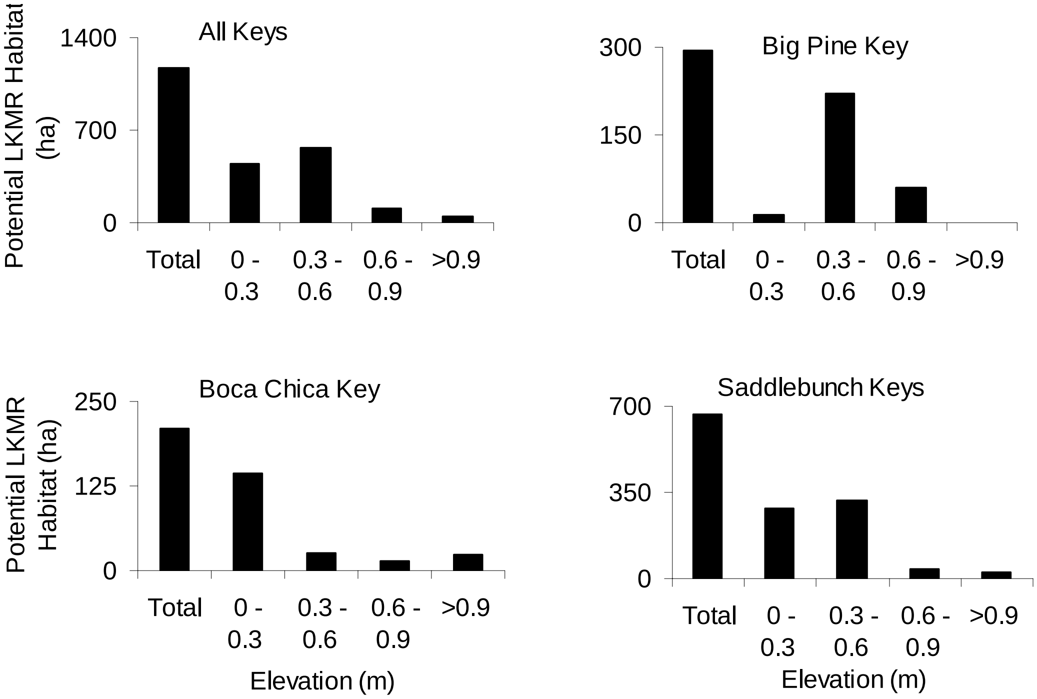


Fig. 3.2. Total potential Lower Keys marsh rabbit (LKMR) habitat (ha) under current conditions. Potential LKMR habitat includes the following vegetation types: buttonwoods, freshwater marsh, low saltmarsh, and high saltmarsh.

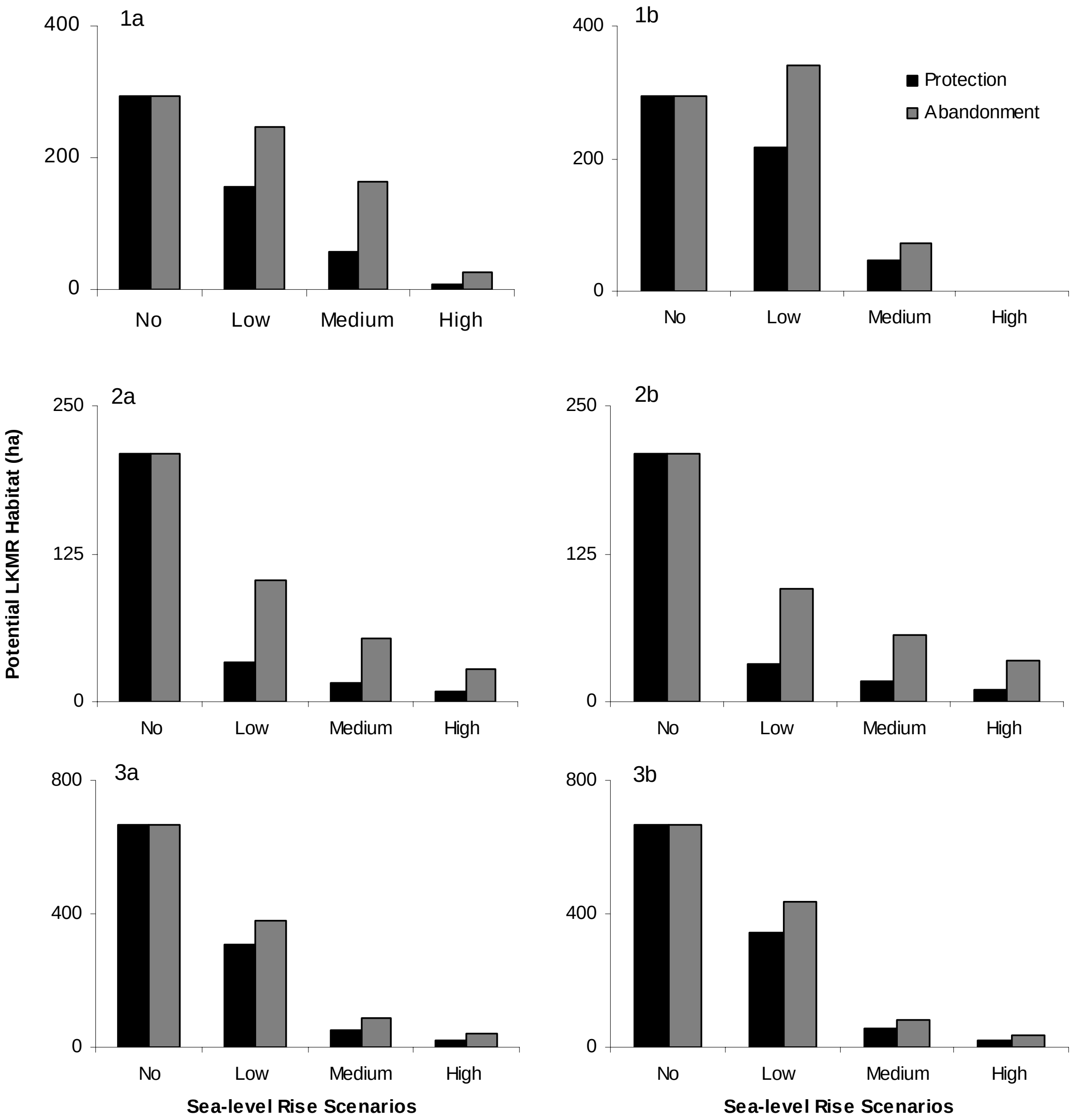


Fig. 3.3. Potential Lower Keys marsh rabbit (LKMR) habitat (ha) under scenarios of sea-level rise, land-use planning, and allowing migration (a) and not allowing migration upslope (b) for Big Pine Key (1), Boca Chica Key (2), and the Saddlebunch/Sugarloaf Keys (3), Florida, USA. Land use planning: protection (black bars) with abandonment (gray bars) of human-dominated areas.

This was true for both migration and no migration treatments (Fig.3.3, graphs 2a and 2b, respectively). When comparing migration and no migration, there was more potential habitat with migration under low sea-level rise and less under medium and high sea-level rise scenarios. Again, as with Big Pine Key, abandonment of developed areas results in more habitat than protection of such areas (Fig. 3.3).

Saddlebunch Keys

The Saddlebunch Keys have 669 ha of potential LKMR habitat with most in the middle elevation category followed by the low, high, and highest categories, respectively (Fig. 3.2). As with the above Keys, the amount of habitat decreased with increasing sea-level rise for both protection and abandonment with a greater decrease due to protection. This was true for both migration and no migration (Fig. 3.3, graphs 3a and 3b, respectively). When comparing migration and no migration treatments I found no clear trends (i.e., the results depended on both treatment and land-use decision; Fig.3.3, graphs 3a and 3b). Lastly, as with Big Pine Key and Boca Chica Key, abandonment resulted in more habitat than protection of developed areas (Fig. 3.3).

Overall Trends

Not surprisingly, under migration and no migration, and both land-use planning decisions (protection and abandonment), I found a general trend of decreasing total potential LKMR habitat with increasing sea-level rise (Table 3.1).

The only clear pattern when comparing migration and no migration for all 3 metapopulations was that no migration resulted in more potential habitat under low sea-level rise, and migration resulted in more habitat under medium and high sea-level rise (Table 3.1). Abandonment of developed areas resulted in more potential habitat than protection under all sea-level rise scenarios and treatments (Fig. 3.3).

I also found the greatest relative decrease in potential habitat to occur between low and medium sea-level rise followed by medium and high sea-level rise, and no and low sea-level rise (Table 3.1). This held true except for migration with abandonment, where the greatest difference was between medium and high sea-level rise followed by the difference between low and medium and no and low sea-level rise, respectively (Table 3.1). Using changes in potential habitat and current population estimates of LKMRs, we found 42–223 rabbits under low sea-level rise, 10–79 under medium sea-level rise, and 2–24 under high sea-level rise (Table 3.2).

Table 3.1. Total area (ha) of potential Lower Keys marsh rabbit habitat on Big Pine Key, Boca Chica Key, and the Saddlebunch/Sugarloaf Keys under scenarios of future sea-level rise, migration or no migration of vegetation upslope, and protection or abandonment of developed areas.

	Migration		**No Migration**	
Sea-Level Rise Scenarios	Abandonment	Protection	Abandonment	Protection
No	1,172	1,172	1,172	1,172
Low	729 (*1.5*)	496 (*2.5*)	871 (*1.5*)	594 (*2*)
Medium	307 (2.5)	123 (*4*)	210 (*4*)	119 (*5*)
High	94 (*3.5*)	40 (*3*)	70 (*3*)	29 (*4*)

* Numbers in parentheses indicate the relative decrease in habitat between sea-level rise scenarios.

Table. 3.2. Total number of Lower Keys marsh rabbits under scenarios of future sea-level rise, migration or no migration of vegetation upslope, and protection or abandonment of developed areas. The proportional change in habitat was used to calculate the proportional change in Lower Keys marsh rabbit population.

	Migration		**No Migration**	
Sea-Level Rise Scenarios	Abandonment	Protection	Abandonment	Protection
No	100 - 300	100 - 300	100 - 300	100 - 300
Low	62 - 187	42 - 127	74 - 223	51 - 152
Medium	26 - 79	10 - 31	18 - 54	10 - 30
High	8 - 24	3 - 10	6 - 18	2 - 7

DISCUSSION

Not surprisingly, the future is bleak for the LKMR, an endemic insular species, under rising sea levels. If the primary cause of the LKMR's decline is habitat loss (USFWS, 1999), further loss due to rising sea-levels may exacerbate this issue. In 1996 the LKMR Recovery Team issued 4 main recovery objectives: (1) acquisition of suitable habitat, (2) control of predation by feral and domestic cats, (3) monitoring of existing populations, and (4) reintroduction to unoccupied suitable habitat (USFWS, 1999). Interestingly, there is no mention of global climate change and sea-level rise in these objectives nor anywhere in the recovery plan for this species (USFWS, 1999). Other endemic and insular species of the Florida Keys also will be impacted by rising sea levels. Global climate change may inhibit recovery efforts of endangered species such as the Florida key deer (*Odocoileus virginianus clavium*), endangered silver rice rat (*Oryzomys palustris natator*), and LKMR as well as cause the disappearance of endemic species such as the key ringneck snake (*Diadophis punctatus acricus*), keys mole skink (*Eumeces egregious egregious*) and striped mud turtle (*Kinosternon baurii*) before much is known about these species. State and federal natural resource responsible for coordinating the conservation of threatened and endangered species can no longer take the static approach of protecting suitable habitat because what is suitable now may not be in the future as climate changes (Midgley et al., 2002; Pyke, 2004).

There are 3 important findings from our research. First, the rate of sea-level rise (or climate change in general) is very important. I found less loss in habitat when vegetation migrates upslope than when it does not. This is not surprising as migration appears to have been the primary way that species responded to past climate change (Noss, 2001; Bush et al., 2004). This result indicates that the rate of rising sea levels is important in determining the impact of global climate change on coastal species and ecosystems. If the rate of sea-level rise is slow enough, the vegetation will be able to migrate upslope in response (i.e., my migration scenarios) and the loss of habitat and species will be reduced. However if the rate is greater than the historic variability of a system, species may not be able to keep up with the change (i.e., my no migration scenarios) and the loss of habitat and species will be much higher. As Noss (2001) pointed out "The challenge for conservationists is not to prevent change. It is to keep rates, scales, and intensities of change in ecosystems within the historic range of variability for those systems – or, at least, to come close" (p. 580).

The second finding is that magnitude of sea-level rise is important. This is an intuitive conclusion, but one that has important implications for biodiversity and ecosystem management. I found increasing impacts with increasing sea-level rise as would be expected, but I also found the greatest impact occurred from the medium sea-level rise scenario. This makes sense as the majority of potential Lower Keys marsh rabbit habitat occurs at the elevation most affected by a medium rise in sea level.

The third finding is that abandonment of human dominated areas (i.e., development and roads) is important for coastal biodiversity conservation. Abandonment should allow coastal plant communities to migrate more easily upslope as opposed to being squeezed between anthropogenic land barriers and rising sea levels (Feagin et al., 2005) as will happen when we protect human-dominated areas (Titus, 1991). My approach indicates that under all sea-level rise scenarios and treatments (i.e., migration vs. no migration), abandonment results in more habitat than does protection. This is a non-surprising result, but it illustrates that importance of land-use decisions under global climate change and rising sea levels. There has been a dramatic decline in coastal wetlands in places like China and the Netherlands, where people have protected development (i.e., built dikes) for centuries (Titus, 1991). Local and regional land-use decisions will have a dramatic impact on how ecosystems and species respond to global climate change.

In conclusion, conservation strategies at multiple scales need to be implemented in order to reduce the impact of global climate change on biodiversity and endangered species. At the regional level, managers must consider land-use planning needs that take into account the needs of both humans and biodiversity. Lastly, at the local scale those agencies that are in charge of endangered species conservation and ecosystem management need to rethink static approaches to conservation or else stand by and watch ecosystems degrade and species go extinct. The can be accomplished by bioclimatic reserve systems that protect climatically representative areas for a given species or suite of species (Pyke and Fischer, 2005). In particular, climatically under-represented areas need to be included in conservation planning along with the standard concerns of threat, opportunity, connectivity, and viability (Pyke, 2004). These areas also need to be connected by corridors of habitat to allow the dispersal needed to adjust to climate change (Pearson and Dawson, 2003). Organisms and communities of organism must have the opportunity to adjust to human-induced climate change or they may face another wave of extinction.

CHAPTER IV

CONCLUSIONS AND IMPLICATIONS

The purpose of this chapter is to summarize the findings of my thesis and the implications of these results. It begins with a summary of results from the above chapters, and proceeds to the implications for conservation in the short and long term in the Lower Florida Keys.

RESEARCH HIGHLIGHTS

Overall, the outlook for the Lower Keys marsh rabbit (*Sylvilagus palustris hefneri*; LKMR) metapopulation on Boca Chica Key is dismal without future conservation actions. Under all 3 scenarios, including no action, the LKMR metapopulation on Boca Chica Key is at high risk of extinction, with the population viability analysis predicting extinction within 10 years. This indicates that conservation action is needed if this metapopulation is to persist into the future. With a finite rate of increase below 1.0, this metapopulation is declining. This combined with the majority of subpopulations being below carrying capacity (i.e., 22 of 25 are below carrying capacity), and my simulation results provides evidence that cat predation is a major factor in the decline of this endangered species. Modeled effects of conservation measures such as cat control provide hope for the persistence of this metapopulation as all 3 scenarios with cat control increased persistence time and decreased extinction risk.

This is not surprising, as feral cats have been found to be the cause of species extinctions on islands throughout the world.

CONSERVATION IMPLICATIONS

Both of my chapters highlight 2 important lessons for conservation biologists and managers: (1) threats often occur at multiple scales and it is important to take a multi-pronged approach to conservation, and (2) simply protecting habitat may not conserve biodiversity and imperiled species. The first lesson is reinforced by Chapters II and III as they each present a threat but at different spatial and temporal scales. The population viability analysis on Boca Chica Key indicated that the most immediate threat to the LKMR on that island is the feral cat. This study was small spatially (as it included only 1 metapopulation) and temporally (as it investigated immediate extinction risks), but has broader implications for imperiled species. Although habitat loss and alteration are considered the greatest threats to biodiversity, demographic features of a population (e.g., survival and fecundity) also should be considered when planning for conservation and the recovery of endangered species. Rising sea levels present a much broader spatiotemporal threat to the LKMR. Sea-level rise will affect the entire range of the Lower Keys marsh rabbit and will occur over a long time period, thus the model took a more course approach over a broader geographic area that the population viability analysis. The lesson learned from these 2 chapters is that the most immediate threat is the feral cat, but that in the long-term sea-level rise will become an important factor in the persistence of this species.

The second lesson also is reinforced by Chapters II and III as both indicate that protection of habitat may be too narrow of an action to evade extinction of the LKMR. The results of the population viability analysis indicate that predator control may be a more important factor than habitat conservation for recovery on Boca Chica Key. I found that 22 out of 25 subpopulations are currently under carrying capacity, most likely due to predation pressure. If current habitat patches are not saturated with individuals, increasing habitat conservation will result in little or no positive impact. Conservation of habitat is often cited as one of the most important part of conservation planning (Noss, 2003; Guenette and Villard, 2005; Peralvo et al., 2005). Although I do not dispute the importance of habitat conservation, my simulation results suggest that predation pressure may be a more immediate threat for some species. I suggest that demographic features of a population (e.g., survival and fecundity) should also be considered when planning for conservation and the recovery of endangered species. My sea-level rise simulations also indicate that protecting habitat for a species or suite of species *in situ* may not be enough as changes occur due to global climate change. Biological reserve systems need to focus on protecting environmentally representative samples of habitat in order to cope with changes due to global climate change (Pyke and Fischer, 2005). Simply protecting habitat and habitat corridors may not be enough for the conservation of some species. The challenge faced by conservationists under global climate change is daunting, but I believe this challenge can be met.

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VITA

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I was born on 16 September 1979 to Jane Winand LaFever and Howard Benson LaFever, and lived my first 18 years of life in the quaint upstate New York village of Cazenovia. I attended Virginia Polytechnic Institute and State University in Blacksburg, VA where I received a Bachelor of Science degree in wildlife science in 2002. I have been married to the multifaceted and supremely-talented Kristin Elizabeth LaFever since 14 August 2004. I have worked in both aquatic and terrestrial systems, and with a variety of organisms including aquatic invertebrates, fish, salamanders, lizards, rattlesnakes, burrowing owls, and the Lower Keys marsh rabbit while working for the US Forest Service, Virginia Polytechnic Institute, Utah State University, and Texas A&M University. I also received Texas state certification for teaching life sciences (grades 8-12) in 2005, and coached high school boys' soccer. Degrees from Texas A&M University will include a M.S. in Wildlife and Fisheries Sciences in August 2006, and a M.Ed. in Curriculum in December 2006. I am interested in conservation initiatives that are holistic in their approach, effective communication of science and environmental issues, and science and environmental education at all levels (both formal and informal). I can be reached at dlafever@tamu.edu or at his permanent address of 3912 Mosley Rd. Cazenovia, NY 13035.