

EFFECTS OF HABITAT DEGRADATION ON MONTHLY
MOVEMENTS OF JUVENILE SNAIL KITES

By

ANDREA CATHERINE BOWLING

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2009

© 2009 Andrea Catherine Bowling

To All Who Supported Me

ACKNOWLEDGMENTS

I would like to thank my major advisor, Wiley Kitchens, who sometimes kept me sane and who, at other times, pushed me towards the blurry line between the sane and the not-so-much-so. He is an extremely knowledgeable ecologist who never let me forget about the importance of asking the right questions. I would like to thank Julien Martin who constantly made me think about the most appropriate way to go about things. He kept me on my toes and made me make all the right decisions. I would like to thank Ken Meyer who was integral in reminding me that the object of my research is a living organism about which we still have a lot to learn. He has shared with me his extensive knowledge on raptors and radio-telemetry, and opened my mind to all the questions still to answer. I would like to thank my fellow student, Althea Hotaling, without whom, I would have had a much greater struggle towards the end point. She has been an important person in problem solving, decision making, and altogether, just keeping my analysis going (and going and going). I would like to thank fellow students Zach Welch, Chris Cattau and Brian Reichert for all the helpful, thought-provoking conversations. I would like to thank all of those important people in the field who helped collect the data that I was lucky enough to inherit. Rob Bennetts collected all the radio-telemetry data from the 1990s. There were many people before and during my time on the crew who assisted in the data collection and the painstaking data entry in the 2000s: Derek Piotrowicz, Samantha Musgrave, Michaela Speirs Grice, Christina Rich Kleberg, Chris Cattau, Danny Huser, Melinda Conners, Sara Stocco, Paul Pouzergues, and Andrea Ayala. Joan Hill and Donna Roberts have made it possible, with their wonderful administrative expertise, to keep this project going. This project would not have been possible without the funding and support from the United States Army Corps of Engineers, Florida Fish and Wildlife Conservation Commission, United States Fish and Wildlife Service, and St. John's Water Management District.

TABLE OF CONTENTS

	<u>page</u>
ACKNOWLEDGMENTS.....	4
LIST OF TABLES.....	7
LIST OF FIGURES	8
ABSTRACT.....	9
CHAPTER	
1 RAPTORS, MOVEMENTS, AND WETLAND HABITAT CHANGE	11
Introduction	11
Raptors	12
Juvenile Raptors	13
Movement	14
Sex-Biased Dispersal	14
Habitat Fragmentation and Habitat Degradation	15
Movement to and from Habitats of Differing Qualities	16
Food Specialists.....	16
Wetlands	17
2 THE EVERGLADES AND THE SNAIL KITE.....	18
Introduction	18
The Everglades	18
Historic Ecosystem.....	18
Altered Hydrology	19
Current Restoration Efforts.....	19
Snail Kite	20
3 MOVEMENT PROBABILITIES OF AN ENDANGERED SPECIES IN A MANAGED AND DEGRADED ECOSYSTEM.....	25
Introduction	25
Predictions	28
Materials and Methods.....	32
Study Area.....	32
Radio Location Data Collection	33
Data Analysis	34
Maximum likelihood estimation	34
Multistate models	35
Radio-transmitters and detection probability	37

Multiple multistate models for multiple spatial scales	38
Parameter index matrices and design matrices.....	38
Model selection	41
Effect size	41
Results.....	42
Connectivity	42
Fragmentation	43
Habitat Degradation: High-Quality vs. Low-Quality Eras	44
Habitat Quality and Fragmentation	45
Age and Sex-Biased Movements.....	45
Discussion.....	46
Connectivity	47
Fragmentation	48
Habitat Degradation: High-Quality vs. Low-Quality Eras	49
Habitat Quality and Fragmentation	51
Age and Sex-Biased Movements.....	52
Natal Area Implications for Movement.....	52
Conclusions and Conservation Implications.....	53
Recommendation for adaptive management	55
APPENDIX SURVIVAL AND DETECTION FROM TOP MODEL OF AMONG REGION MOVEMENT	67
LIST OF REFERENCES	68
BIOGRAPHICAL SKETCH	75

LIST OF TABLES

<u>Table</u>	<u>page</u>
3-1 Movement within the Everglades region.....	57
3-2 Movement within the Kissimmee Chain of Lakes region.	58
3-3 Movement among all regions.	59
A-1 Estimates for survival (S) and detection (p) among all regions from the top model: S[b(.)a(.)] p[b(r)a(r)] psi[b(AR+d)a(r)].	67

LIST OF FIGURES

<u>Figure</u>	<u>page</u>
2-1 The five major wetland regions utilized by the snail kite in Florida	24
3-1 Conceptual relationship between movement probabilities of snail kites along a food-resource gradient	60
3-2 Monthly movement probabilities of adult and juvenile kites in the pre-degradation system	60
3-3 Movement across different levels of contiguity.	61
3-4 Movement within and out of major wetland regions.	61
3-5 The effect size between seasonal movements in the Kissimmee Chain of Lakes.	62
3-6 The sum of the movement probabilities from each wetland within the Everglades region.	63
3-7 Movements within the Everglades pre-degradation vs. post-degradation.	63
3-8 The effect size between movements in the system pre-degradation and post-degradation.	64
3-9 Within the Kissimmee Chain of Lakes: the top 7 models (with 75% of the weight).	64
3-10 Sum of the movement probabilities from each major wetland region and the periphery.	65
3-11 All movement probabilities among the regions and the periphery.	65
3-12 The effect size of the movement probabilities among the regions and the periphery.	66

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

EFFECTS OF HABITAT DEGRADATION ON MONTHLY
MOVEMENTS OF JUVENILE SNAIL KITES

By

Andrea Catherine Bowling

May 2009

Chair: Wiley M. Kitchens

Major: Wildlife, Ecology, and Conservation

Habitat degradation is a form of habitat loss that many organisms are currently experiencing. Wetlands are particularly susceptible to degradation and the Everglades ecosystem of Florida is not excluded from this trend. Species that depend entirely upon one or few habitat types within an ecosystem suffer the greatest when their sole resource starts disappearing. The snail kite is such a species as it forages best from sparse emergent vegetation on almost exclusively one species of freshwater snail . The Everglades ecosystem has suffered habitat degradation due to vegetative community conversion and disrupted hydrology. Pre-degradation and post-degradation movements have been compared for juvenile snail kites using radio-telemetry in the early 1990s and the early 2000s. The snail kite has been forced to move around more in search for appropriate foraging opportunities after the habitat degradation of the late 1990s. The juvenile population has experienced higher movement probabilities overall, and especially out of the most historically important wetlands. Juveniles are moving out of the Everglades region and the Lake Okeechobee region significantly more than they did pre-habitat degradation. They are also moving into the West Palm Beach portion of the Loxahatchee Slough from most other regions at a significantly higher probability. Higher movement rates could be troublesome for the physiological health of the individuals who are not able to replace the energy

lost in transition with the energy gained in foraging once foraging opportunities are found. This could have detrimental effects on survival and reproduction for this endangered species as it is imaginable that it could have on any species. Habitat degradation in the Everglades ecosystem must not occur and must be reversed with restoration for this imperiled and other imperiled species to continue as a part of the ecosystem.

CHAPTER 1
RAPTORS, MOVEMENTS, AND WETLAND HABITAT CHANGE

Introduction

Falconiform raptors are a group of vertebrates that are of special conservation concern. Birds of prey are long-lived and have small broods (Brown, 1977). Because of these characteristics, juvenile recruitment is especially important to sustaining populations (Harmata et al., 1999). Being able to fledge young successfully and have those young survive to adulthood takes tremendous energy on the part of, first the parents, then the juveniles themselves. Most birds of prey are not food specialists (Newton, 1979). In fact, reversed size dimorphism between the sexes, allows a single species to exploit different food sources (Brown, 1977, Newton, 1979). However some species, like the snail kite, depend on one kind of food and must move to where the food occurs if the current food source is no longer sustaining foraging needs. Most birds of prey migrate in response to factors including food availability, but some, including the snail kite, move nomadically in response to unpredictable food resources (Newton, 1979). Habitat fragmentation affects how a species can move in response to availability of prey (Pickett and Cadenasso, 1995, Smith and Hellmann, 2002), and degradation of habitat directly affects prey availability. Movements occur at a higher rate away from lower-quality degraded habitats and towards higher-quality habitats (Senar et al., 2002, Pettorelli et al., 2003, Boudjemadi et al., 1999). Wetlands are habitats that have been lost and degraded at an enormous rate (Mitsch and Gosselink, 2007). Wetlands have been filled in, polluted, and robbed of their water, and they have experienced vegetative community changes (Mitsch and Gosselink, 2007). The Everglades is such a wetland ecosystem that has experienced all such problems. Such degrading changes will negatively affect species, including the snail kite, that depend on wetlands for their entire life cycle.

The first chapter of this document addresses the general ecology of raptors, juvenile members of a population, movements, habitat fragmentation and degradation and the effects of these habitat changes on movements, food specialists and the consequence of depending on one prey species when habitats change, and wetland ecosystems that have experienced much habitat change and degradation due their vulnerable nature. The second chapter puts all of the topics addressed in the first chapter in the context of the Everglades and the snail kite. The third and final chapter describes my predictions, methodology, results, and discussion.

Raptors

Raptors occur worldwide except in Antarctica and many small oceanic islands (Brown, 1977), and the 287 Falconiform species live in almost every known habitat (Brown, 1977). Some raptors can exploit more than one habitat while others are mostly confined to one main habitat (Brown, 1977). Raptors are diurnal; they hunt mainly using their binocular eyesight, but must rotate their heads on a flexible neck to see around all sides (Brown, 1977). Their taloned feet are for killing and holding prey, and their hooked beaks are for tearing flesh. Raptors are powerful fliers, using their tails for steering (Brown, 1977).

Raptor populations usually have a sex ratio of 50:50 (Newton, 1979). Most raptors are monogamous (Newton, 1979), exhibit mating displays, build their own nests, and lay 3 or fewer eggs (Brown, 1977). Falconiform species tend to nest in the same place in subsequent years, and nesting pairs usually have favored perches in the nesting area (Newton, 1979). The size of a nesting pair's home range is related to prey availability and may or may not overlap the ranges of other pairs' (Newton, 1979). Incubation periods are generally rather long (e.g., 25 to 40 days) with the female incubating more than the male (Brown, 1977).

Falconiforms exhibit reversed size dimorphism in that the female of the species is larger in body size than the male (Brown, 1977, Newton, 1979). This reversed size dimorphism is

associated with feeding habits, and the degree of size difference between the female and male of a species is linked with such habits in that the faster and more agile the prey, the greater the degree of difference in size between the sexes (Newton, 1979). Seventy five species live almost exclusively on a single kind of prey, and among them, the occurrence of dimorphism increases with increasing swiftness and nimbleness of their prey (Newton, 1979).

Most raptors are solitary (or low-density) nesters, but some nest in (loose) colonies (Brown, 1977). The solitary nesters experience “fairly evenly distributed and predictable” food sources (Newton, 1979), while the colonial nesters experience “clumped and unpredictable” food availability (Newton, 1979). The colonial nesters are mainly insectivorous, carrion eating, or nomadic (Brown, 1977). Availability of nests sights may also determine whether nesters are spaced-out solitary nesters or clumped colonial nesters. Nestlings of most raptor species do not display siblicide, and the parents continue to feed their young for a period of time post-fledging (Brown, 1977).

Outside of the breeding season, raptor foraging behavior differs among species. Raptors that nest solitarily during the breeding season tend to occupy individual foraging ranges outside of the breeding season (Newton, 1979). Colonial nesters tend to occupy communal night roosts outside of the breeding season but hunt individually (Newton, 1979). Dense colonial nesters tend to occupy communal night roosts and forage gregariously outside of the breeding season (Newton, 1979). These foraging raptors include both adult and juvenile members of populations. Juveniles must learn and gain experience in capturing prey on their own outside of the nest in order to survive to adulthood.

Juvenile Raptors

Juvenile recruitment is essential to sustaining an animal population (Harmata et al., 1999). Recruitment into the adult population only occurs if juveniles find appropriate habitat with

enough food resources and survive until they begin reproducing. Within species, differences occur in dispersal distances due to availability of prey and vacant nesting sites (Newton, 1979). Movements among a mosaic of habitats to find food resources are an extremely important aspect of the juvenile's ecology. After fledging, raptors have a high fidelity to their natal sites (Newton, 1979). Juvenile movements (Ferrer, 1993) and habitat choice (Nijman and van Balen, 2003) are markedly different from adult conspecifics and influence recruitment (Ferrer, 1993).

Movement

Movement of organisms occurs in many forms, probably has genetic determinations (Harmata et al., 1999), and can be closely tied to changes in food supply (Newton, 1979). Organisms move across their range, and the study of this movement is important to how connectivity and habitat quality influence survival (Boudjemadi et al., 1999). The most widely studied (and perhaps the most common) form of raptor movement is migration. However, some raptor species exhibit nomadism, which occurs more frequently in subtropical and tropical environments than in temperate (Brown, 1977) and is defined by Newton (1979) as movement "in which birds drift from one area to another, residing for a time wherever food is temporarily plentiful." Nomadism occurs in response to fluctuating and unpredictable changes in prey availability (Brown, 1977, Newton, 1979). Sociality is also a possible indicator of nomadism, in that gregarious birds tend to display nomadic movements (Brown, 1977). Movements often differ among differing members of a population as previously mentioned between juveniles and adults; movements also often differ between females and males.

Sex-Biased Dispersal

It is widely known that most avian species exhibit a female bias in dispersal (Greenwood and Harvey, 1982) both in distance moved or proportion of individuals moving (Clarke et al., 1997). However, sex-biased dispersal does not occur in all raptors (Newton, 1979), and within

Accipitridae, more males than females disperse, versus Falconidae, in which species adhere more to the avian norm of female dispersal (Newton, 1979). Both sexes of nomadic species tend to disperse (Greenwood and Harvey, 1982), but communal breeders have a very large female bias in natal dispersal (Greenwood and Harvey, 1982). As it has been shown that movement probabilities are different between sexes and ages, and the type of movement a species displays is a result of feeding and breeding ecology, when individuals of a population experience unnatural changes to the habitat in which they forage and over which they move, movements are likely to change.

Habitat Fragmentation and Habitat Degradation

Habitats change due to a number of process including fragmentation and degradation. Habitat fragmentation is a catch-all term. It has been defined as the process that includes habitat loss, habitat conversion, and the breaking apart of habitat (Fahrig, 2003). Habitat fragmentation is a leading “culprit in the present extinction crisis” (Boudjemadi et al., 1999) and can occur due to a number of different processes. Habitat loss usually results in breaking up a once large and contiguous tract of land into smaller pieces separated from each other by an area that is no longer considered habitable. Habitat conversion can be classified as a loss of a particular type of habitat. Fragmentation can occur without the loss of habitat. Structures (road, levee, canal, etc.) can impede the movement of organisms (Pickett and Cadenasso, 1995) from one patch to another, effectively fragmenting the habitat. Fragmented habitat results in a habitat configuration (Fahrig, 2003) that impedes organisms’ ease of movement (Smith and Hellmann, 2002) across the landscape and across their natural/realized home ranges (Martin et al., 2006). Fragmentation can also occur due to degradation of habitat in that essential qualities of that habitat are lost. Available food resources can be a measure of habitat quality used to understand

the occurrence and level of habitat degradation, and movement of organisms can be an indication of availability of food resources.

Movement to and from Habitats of Differing Qualities

Movement can be an indication of habitat quality. Environmental condition dependence dispersal is often due to habitat quality, and organisms often are “adaptive to react to a local deteriorating food resource by dispersing” (Ims and Hjermann, 2001). Seasonality of resources also forces individuals to disperse in order to find resources elsewhere. Poor habitat quality will force organisms out towards higher quality habitat (Senar et al., 2002, Pettorelli et al., 2003) that can better support their physiological needs. If the habitat quality is also low in the area to which an organism has moved, it will need to continue dispersing until it is able to find an area that has sustaining resources: high quality habitat (Boudjemadi et al., 1999). “Dispersal may be viewed as a way by which organisms can escape unfavourable environmental conditions by means of spatial displacement (Ims and Hjermann, 2001),” but is costly in “terms of fitness-related traits such as survival (Ims and Hjermann, 2001).” An increase in movements across the range of the snail kite would be an indication of decreased habitat quality (Bennetts and Kitchens, 2000) and could be costly to fitness (i.e. survival). As prey limitations in a poor quality habitat will force an organism to find a higher quality habitat with more available prey, this situation is more problematic for food specialists, like the monophagous snail kite, than generalists that have a larger food base.

Food Specialists

Monophagous organisms feed on only one species or on several closely related species (Begon et al., 2006). Such food specialists tend to have the following characteristics: short life span, specialized anatomical structures, and a higher probability of local extinction (Begon et al., 2006). This higher probability of local extinction could be at least partially due to essential prey

being limited to specific habitats (Begon et al., 2006). Few predators are monophagous, but for those that are, the “handling times [of their prey items] are long relative to their search times” (Begon et al., 2006), and the environment from which they catch their prey is relatively productive (Begon et al., 2006) like wetlands.

Wetlands

Wetlands are intermittently or permanently flooded ecosystems with constantly changing water levels that usually occur at the interface of terrestrial upland ecosystems and deepwater aquatic ecosystems (Mitsch and Gosselink, 2007). Hydrology is the most important aspect of wetland ecology. It is affected by precipitation, evapotranspiration, surface inflows and outflows, groundwater, and, in some instances, tides (Mitsch and Gosselink, 2007). Hydrology influences soil and water chemistry and transports sediments, nutrients, and toxins (Mitsch and Gosselink, 2007). When the aforementioned physiochemical environment is affected, the biota responds. As a result, minimal changes in hydrology can result in considerable changes in the biota (Mitsch and Gosselink, 2007). Hydrology affects wetland features and functions such as: vegetative community composition, primary productivity, organic matter accumulation, and nutrient cycling and availability (Mitsch and Gosselink, 2007). Because of wetlands’ sensitivity to hydrologic changes, these ecosystems are extremely susceptible to habitat degradation.

CHAPTER 2 THE EVERGLADES AND THE SNAIL KITE

Introduction

The Everglades is an expansive wetland that has suffered the effects of habitat loss and degradation (McPherson and Halley, 1996, Sklar et al., 2002). The snail kite depends on the fragmented and degraded Greater Everglades Ecosystem for the entirety of its lifecycle. Snail kites are monophagous (Beissinger, 1990), nearly monomorphic in size (Newton, 1979), nomadic (Bennetts and Kitchens, 2000), and sensitive to wetland degradation (Beissinger, 1995, Bennetts and Kitchens, 2000, Martin et al., 2006).

The Everglades

Historic Ecosystem

The subtropical Everglades watershed once extended from the shallow-water Kissimmee Chain of Lakes in central Florida to the Florida Bay in south Florida and included the Kissimmee River flood plain, Lake Okeechobee and the 809,000 hectares (McPherson and Halley, 1996) of freshwater peatland marshes in between. During the dry season, lakes and wetlands were isolated from each other, but during the wet season, June to September (McPherson and Halley, 1996), lakes would overflow, the Kissimmee River would flood, and Lake Okeechobee would spill over its banks sending water to the freshwater marshes in a slow sheet flow down the southward slope of about five centimeters per 1.6 kilometers (McPherson and Halley, 1996). The Atlantic Ridge helped contain the freshwater in the Everglades causing a long hydroperiod which allowed peat building (McPherson and Halley, 1996). Hydrologic flow is arguably the most important factor in shaping the landscape features of the Everglades. The most extensive landscape type is ridge and slough, characterized by a wet-to-dry hydrologic gradient of sloughs to wet prairies to sawgrass strands to tree islands. These communities formed in an alignment

that was parallel to the direction of flow (McPherson and Halley, 1996). In its natural state, the Everglades was a spatio-temporally varying environment.

Altered Hydrology

The Everglades is drastically different than it once was. The ecosystem is half of its original expanse (Sklar et al., 2002) due to over 2250 kilometers of primary canals and over 100 water control structures. Canals, levees and control structures were built to drain land for agriculture, urban development, transportation, and consequently for flood control purposes in the forms of mass storage and mass drainage to protect the aforementioned three investments (McPherson and Halley, 1996, Sklar et al., 2002). This hydrologic interruption has led to soil subsidence, landscape fragmentation, functional and spatial habitat loss (McPherson and Halley, 1996), falling water tables, peat fires, altered hydroperiods, impounded wetlands, reduced water quality, reduced wildlife, reduced terrestrial habitat in the form of tree island loss, and invasion of nonnative plants (Sklar et al., 2002).

Water quality has been degraded in this altered ecosystem due to nutrient loading, pesticide, herbicide and heavy metal contamination. The sources of these contaminants include upstream agricultural fields, cattle operations, and landfills (McPherson and Halley, 1996). These pollutants lead to algal blooms, invasive species take-overs, and biomagnification of mercury in wildlife (McPherson and Halley, 1996, Sklar et al., 2002).

Current Restoration Efforts

In 1992 and 1996, the United States Army Corps of Engineers (USACE) was given the authority by the Water Resource Development Acts to evaluate the ecosystem under the altered hydrology and come up with a plan to restore the ecosystem. The Water Resource Development Act of 2000 provided the Comprehensive Everglades Restoration Plan (CERP) as a framework and guide for the USACE to modify managed hydrology to include ecosystem restoration as a

priority alongside flood control and water supply. Scientists from many disciplines helped develop the plan and their work continues to be the cornerstone of restoration progress.

Even as restoration efforts are underway, some studies (Martin et al., 2003, Havens and Gawlik, 2005, Ogden, 2005, Johnson et al., 2007, Zweig, 2008, Karunaratne et al., 2006) indicate further habitat degradation has occurred in the late 1990's. In certain areas this habitat degradation has been caused by prolonged hydroperiods that induced habitat conversion to a deeper, more aquatic system overall (Kitchens et al., 2002, Zweig, 2008). The conversion has left apple snails inaccessible to foraging snail kites (Bennetts et al., 2006, Darby et al., 2006). Based on many observations of this habitat degradation in the Kissimmee-Okeechobee-Everglades watershed (Kitchens et al., 2002, Martin et al., 2007b), Martin et al. (2008) defined a pre-degradation time period (before and including 1998) and a post-degradation time period (after 1998).

Snail Kite

The snail kite (*Rostrhamus sociabilis plumbeus*) is a raptor whose United States population occurs only in Florida and is limited to the Central and South Florida wetland ecosystems. This species has been intensively studied for decades since its listing as federally endangered by the Endangered Species Act in 1967. The snail kite is currently mostly confined to five major wetland regions and some smaller isolated wetlands. The five main freshwater systems are the Kissimmee River valley, Upper St. John's River, Lake Okeechobee, Loxahatchee slough, and the Everglades, (Sykes et al., 1995) (Figure 2-1).

Snail kites exhibit many characteristics of birds of prey, but also show dissimilarities from other raptors. As are other raptors, snail kites are long-lived and have small broods, so population growth probably is sensitive to juvenile recruitment into the breeding population. Unlike most raptors, the snail kite does not display monogamy within the breeding season.

Either adult within a nesting pair may abandon his/her mate and brood-rearing responsibilities to reneest with a different individual if the original nest has a low probability of failure (Beissinger, 1987). Raptors are, overall, solitary nesters, and a snail kite pair can be found nesting alone, with no other pair nearby, but the majority of nesters build their nests and rear their young in loose colonies with other pairs. Like many other raptors, the snail kite will continue to feed its young after it has fledged from the nest. It will do so for nine to eleven weeks post-fledging. Individual snail kites, like individuals of other raptor species, will exhibit natal fidelity (Bennetts and Kitchens, 1997a, Martin et al., 2007c). This raptor is diurnal and hunts its prey using its eyesight just as all other raptors do, but differs from most other raptors in its gregarious nature in which it will hunt. However, the snail kite differs from most other raptors in that it is a food specialist and therefore only exhibits very slight reversed size dimorphism. This raptor is a wetland dependent species, in that it feeds almost solely on the freshwater apple snail (*Pomacea paludosa*) (Sykes et al., 1995).

The life cycle of the apple snail depends on both hydrology and vegetation structure (Karunaratne et al., 2006, Darby et al., 2008). The ideal foraging habitats of the snail kite are wet prairies and lake littoral zones with sparse emergent vegetation (Bennetts et al., 2006, Bennetts and Kitchens, 1997a). As the snail kite depends on the availability of the apple snails to sustain its survival, it is therefore dependent on the functionality of the entire system: hydrology, vegetative communities, and snail density. As such, the ongoing Comprehensive Everglades Restoration Plan (CERP) has used the snail kite as an indicator of wetland health.

The subtropical Florida snail kites, unlike most other raptors, are nomadic and have been known to move to and from wetland fragments with relative ease (Beissinger and Takekawa, 1983, Sykes, 1983, Takekawa and Beissinger, 1989, Bennetts, 1993, Bennetts and Kitchens,

1997b, Martin et al., 2006) in response to factors such as food availability and drought. Thus, they may stay in a certain wetland for extended periods of time while conditions are favorable, move on to another place during unfavorable times and move back again in response to better conditions (Sykes et al., 1995). Therefore, while their range is restricted due to the extreme specialization of their diet, within their range they have shown considerable movements.

The snail kite population in Florida suffered a large decline due to the 2001 drought and has failed to recover since. Survival and population size estimates have continued to decrease, with drought years having a prominent effect (Martin et al., 2007b). The failure of the population to recover after this crash is a strong indication of the habitat degradation in the Kissimmee-Okeechobee-Everglades watershed (Kitchens et al., 2002, Martin et al., 2007a, Martin et al., 2008). The number of juvenile snail kites dramatically decreased after 1998 (Martin et al., 2007b), and juvenile survival has appeared to decrease since 1999 (Martin et al., 2006). I hypothesized, therefore, that small- and large-scale movements of juvenile snail kites differed between the pre-degradation and post-degradation time periods. Increased movements also should have been associated with habitat degradation in the Everglades (Belisle et al., 2001, Ruiz et al., 2002). Studying the movements of juveniles is important for the endangered snail kite for which recruitment is of utmost importance.

The present study focused on the period 1992 to 2006 and attempts to elucidate how habitat degradation could possibly affect the movement of juvenile snail kite. However, it is worth noting that the snail kite population in Florida has again declined precipitously as shown by the estimate of 685 (+/- 74) (unpublished data) from the 2008 population survey.

Reproduction has become limited essentially to the Kissimmee Chain of Lakes, specifically Lake

Tohopekaliga (unpublished data). Efforts to radio tag and track fledglings are currently underway to determine juvenile survival and recruitment.

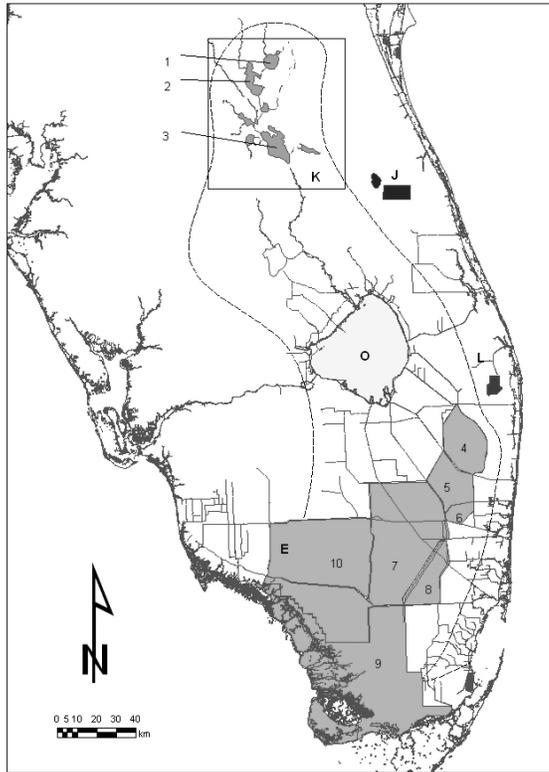


Figure 2-1. The five major wetland regions utilized by the snail kite in Florida. The Kissimmee Chain of Lakes (K), Big Cypress Marsh Complex (Upper St. John’s River) (J), Lake Okeechobee (O), Loxahatchee Slough (West Palm Beach Water Catchment Area/Grassy Waters Preserve) (L), the Everglades (E). Moderately isolated wetlands in the K region are: East Lake Tohopekaliga (1), Lake Tohopekaliga (2), and Lake Kissimmee (3). Contiguous wetlands in the E region are: Water Conservation Areas 1 (4), 2A (5), 2B (6), 3A (7), 3B (8), Everglades National Park (9), and Big Cypress National Preserve (10). (adapted from Martin et al.(2006)).

CHAPTER 3
MOVEMENT PROBABILITIES OF AN ENDANGERED SPECIES IN A MANAGED AND
DEGRADED ECOSYSTEM

Introduction

The movement of organisms throughout their realized niche in space and time is an integral process in population dynamics (Macdonald and Johnson, 2001, Belisle et al., 2001, Clobert et al., 2001). Movement of organisms in a spatially varying landscape keeps the gene pool diverse and protects local populations from extinction (McPeck and Holt, 1992). Movement is an especially important process for juvenile cohorts of a population. Juvenile survival and recruitment, which is essential in maintaining a growing or stable population (Harmata et al., 1999, Cushman, 2006), is directly affected by the ability of juveniles to move across the landscape to find the appropriate habitat to support their physiological needs. Habitat quality is a major factor influencing the movement of organisms (Boudjemadi et al., 1999, Senar et al., 2002, Kauffman et al., 2004, Bennetts and Kitchens, 2000). It is well known that habitat fragmentation causes organisms to move unnaturally about their environment (Belisle et al., 2001, Hinam and Clair, 2008, Haddad, 1999, Macdonald and Johnson, 2001, Martin et al., 2006), but several studies have shown that low-quality habitat forces organisms to depart at higher rates in search of high-quality habitat (Pettorelli et al., 2003, Lenihan et al., 2001, Boudjemadi et al., 1999, Senar et al., 2002, McPeck and Holt, 1992, Ims and Hjermann, 2001). In reality, it is probably a complex combination of both habitat fragmentation and habitat quality (Boudjemadi et al., 1999) which causes organisms to move at particular rates across certain distances.

Habitat quality can be measured by the amount of available prey the habitat supports. When high quality habitats are not abundant in the landscape, organisms are forced to move about at a higher rate and travel longer distances (McPeck and Holt, 1992). As a consequence, they use a great deal of energy, lower their physiological health and possibly negatively affect

their chances for survival (Gear and Burns, 2007, Griffen and Drake, 2008, Ruiz et al., 2002, McPeck and Holt, 1992).

Movements can be used as an indication of habitat quality (Belanger and Rodriguez, 2002) and may differ among different members of a population. Such differences in movement may indicate separate niches, life histories, and habitat requirements among the separate ages and sexes (Greenwood and Harvey, 1982, Nijman and van Balen, 2003).

Habitat quality often degrades as a consequence of anthropogenic activities. Wetlands are particularly susceptible to degradation as they are sensitive to any changes in hydrology (Mitsch and Gosselink, 2007). Water depth, duration, and timing affect the vegetative communities that support faunal life in wetlands. The Everglades ecosystem is an expansive, once contiguous, wetland of international focus and consideration during its current and ongoing restoration phase, as it has been fragmented by compartmentalization and habitat loss to drainage for agriculture and urban environments. The Comprehensive Everglades Restoration Plan (CERP) is the largest restoration project in the world currently underway. The outcome will add to the knowledge bank of how to undergo, or how not to undergo, large-scale restorations for other imperiled ecosystems, including whether or not such attempts are even feasible. Even as scientists have realized the need for restoration of the ecosystem, and managers have begun efforts, further habitat degradation has occurred (Kitchens et al., 2002, Martin et al., 2003, Havens and Gawlik, 2005, Ogden, 2005, Johnson et al., 2007, Martin et al., 2007b, Zweig, 2008, Karunaratne et al., 2006) in all areas of the snail kite's range. Martin et al. (2008) hypothesized that habitat degradation may have increased since the mid-90s, to evaluate their hypothesis they described a pre-degradation time period (before and including 1998) as having higher-quality snail kite

foraging habitat and a post-degradation time period (after 1998) as having lower-quality snail kite foraging habitat.

The snail kite (*Rostrhamus sociabilis plumbeus*) is a wetland dependent species that occurs only in the greater Everglades ecosystem of southern Florida (Sykes et al., 1995). It is wetland dependent, in that the entirety of its lifecycle is supported by wetland species. Snail kites perch and nest over water on woody and herbaceous wetland vegetation (Sykes, 1987b), and they forage over vegetative communities represented strongly by sparse emergent herbaceous plants like *Eleocharis* and *Panicum* (Bennetts et al., 2006). Their diet consists almost exclusively of the aquatic freshwater apple snail (*Pomacea paludosa*) (Sykes, 1987a). However, apple snails probably became largely unavailable to snail kites in low-quality habitats after the wetland degradations of the late 1990s as evidenced by the following. There was a lack of recovery due to low population growth rate following the population decline of 2001 (Martin et al., 2007b), and is in response to both habitat conversion and an increase in drying events (Martin et al., 2008). There has been decreased use of Lake Okeechobee, an area where snail kites have historically occurred and produced successful nests (Martin et al., 2003). Inappropriate timing of drying events in the wetlands within the Everglades ecosystem has led to low snail abundance (Darby et al., 2008). Lack of snail availability to foraging snail kites is directly linked to low snail abundance estimates (Darby et al., 2004). High movements away from the area of “low quality” would also indicate unavailable prey (Boudjemadi et al., 1999, Senar et al., 2002, Kauffman et al., 2004, Bennetts and Kitchens, 2000). Other direct evidence for this would include the following: snail density estimates at sustainable foraging levels, but no foraging kites, or foraging kites not capturing anything. This situation would occur if the snail densities are high in vegetative communities not easily foraged by snail kites, but low in vegetative

communities consisting of sparse emergents representing prime foraging habitat (Bennetts et al., 2006).

To understand the effects of habitat quality on snail kite movement, I compared two time periods. The first represented the pre-decline juvenile population which was utilizing the habitat pre degradation, and the second represented the post-decline juvenile population utilizing the habitat in a post-degradation state of the system. Monthly locational radio telemetry data was collected by aerial surveys on 117 juvenile snail kites during the period of March 1992 through May 1995 and on 149 juvenile snail kites during the period of March 2003 through April 2006. Each location was recorded as a UTM (Universal Transverse Mercator, North American Datum 1983) coordinate in a specific wetland and region. I followed the approaches of Bennetts et al. (1999) and Martin et al. (2006), in that they divided the Everglades ecosystem into five major regions and further subdivided two of those major regions into smaller wetlands and lakes. The impounded wetlands within the Everglades (E) region were considered contiguous in their level of connectivity; the lakes within the Kissimmee Chain of Lakes (K) region were considered moderately isolated in their level of connectivity, and the five major regions were considered isolated in their level of connectivity (Figure 2-1). These connectivity measures are consistent with Martin et al. (2006).

Predictions

The focus of this study was to understand how habitat degradation may have affected movement patterns of juvenile snail kites. Spatial structure and isolation of wetlands have been shown to be important influences of snail kite movements. As such, I also considered the geometric features of the landscape (distances among wetlands, and size of the wetlands) as well as the level of isolation of each wetland. Martin et al. (2006) showed that two measures of fragmentation are good predictors of juvenile snail kite movement: the area of the site to which

snail kites move and the distance between two sites. These fragmentation measures greatly affect the probability that a kite will move to the second site. I used the same metrics to model movement within the two main regions of the kite's range, the Kissimmee Chain of Lakes and Everglades (Figure 2-1), and among all five wetland regions of the kite's Florida distribution (Figure 2- 1). I also reevaluated the hypotheses of Martin et al. (2006) with a new data set. Below are the predictions from Martin et al. (2006):

1. Movement probabilities of juveniles should decrease with distance, and with the size of the donor site. In contrast, movement should increase with the size of the receiving site.
2. Movement of juvenile snail kites should be greater within regions than among.
(“Movement will covary positively with connectivity” of regions.)

In addition to these predictions and of primary interest to my study, I will evaluate the hypothesis that habitat degradation has induced an increase in the movement probabilities of juvenile snail kites in the Everglades ecosystem; low-quality habitat in the post-degradation era, as compared to high-quality habitat in the pre-degradation era, should force juvenile snail kites to move around at a higher rate as they look for foraging opportunities (Boudjemadi et al., 1999, Senar et al., 2002, Kauffman et al., 2004, Bennetts and Kitchens, 2000). Below are three predictions related to this hypothesis.

3. Monthly movement probabilities within groups of wetlands (i.e., the Everglades (E) region and the Kissimmee (K) region), have increased from the pre-degradation time period to the post-degradation time period, and
4. Movement of juvenile snail kites among regions has increased. The post-degradation state of the system indicates that food availability was extremely low in all areas, similar

to conditions during a drought, which initiates the response “leave or starve” (Figure 3-1) (Bennetts and Kitchens, 2000). This is also consistent with the hypothesis that states that starving birds have higher activity levels which tend to increase the likelihood for a bird to leave its natal area (Astheimer et al., 1991).

5. Movement into the periphery (matrix) has increased in the later time period as a function of habitat degradation in the main wetland units. Kites are having to pass through the periphery more often to reach major wetland units and are having to find foraging opportunities in the periphery.

Revisiting the ideas of island biogeography theory and patch dynamics, considering much of the research that has been done on Lake Okeechobee (Johnson et al., 2007, Havens and Gawlik, 2005, Martin et al., 2003, Zweig, 2008), and considering that Bennetts and Kitchens (1997a) hypothesized that snail kites may move through the landscape by using wetlands as stepping stones, I predicted:

6. Movement between K and E has decreased in the post-degradation time period (see Figure 3-2) as Lake Okeechobee has ceased functioning as a productive wetland unit for kite foraging and nesting (2003) and the practical linear distance between K and E has increased without Okeechobee as a stepping stone (Martin et al., 2003, Zweig, 2008). In other words, snail kites may still move to Lake Okeechobee, but because of the poor conditions in this wetland may die before having the chance to move to another wetland.

Juvenile members of a population usually behave differently from, and occupy a separate niche in space and time than, their adult counterparts (Nijman and van Balen, 2003, Ferrer, 1993, Walls and Kenward, 1998, Blums et al., 2003, Senar et al., 2002). It is known that young, newly fledged animals have a lower survival rate than adult individuals of the same species (Bennetts and Kitchens, 1999). It may also hold that younger animals have a much harder time finding prey resources and must search more (Newton, 1979). There is no evidence that juvenile snail kites are able to follow adults to previously unexplored wetlands.

7. Rate of movement of younger snail kites is greater than movement of older snail kites as older birds have more experience with the landscape and can travel to known areas better. Young birds are more likely to find areas that are not suitable to support foraging needs and then are forced to move again.

Males and females of the same species often exhibit different propensities to move (Newton, 1979, Greenwood and Harvey, 1982, Walls and Kenward, 1995, Clarke et al., 1997, Real and Manosa, 2001). It has been shown that many bird species trend toward females moving more than males, and that communal breeders tend to exhibit this female-biased dispersal (Greenwood and Harvey, 1982). Within the raptor groups, accipiter males move more, while falcon females move more, although there have been exceptions to this trend. In some species the sex difference is much more apparent in juveniles than in adults, and although Bennetts and Kitchens (1997a) have found that snail kites have no sex difference in movements, the results were preliminary. Therefore, I predicted:

8. Rate of movement of females is higher than movement of males on both spatial scales.

Materials and Methods

Study Area

Our study area consisted of the five major freshwater wetland regions and the peripheral smaller isolated wetlands in central and south Florida utilized by the snail kite. The five main regions are the Kissimmee Chain of Lakes (K), Big Cypress Marsh Complex (J), Lake Okeechobee (O), Loxahatchee Slough (L), and the Everglades (E) (Figure 2-1). Three large lakes with notable kite habitat in the Kissimmee Chain of Lakes are East Lake Tohopekaliga (1), Lake Tohopekaliga (2), and Lake Kissimmee (3). The Everglades region is further divided into the following smaller patches: Water Conservation Areas 1 (4), 2A (5), 2B (6), 3A (7), 3B (8), Everglades National Park (9), and Big Cypress National Preserve (10). These patches are defined as distinct wetlands within the larger regions following the protocol of Bennetts and Kitchens (1997b), Bennetts et al. (1999), and Martin et al. (2006).

The wetlands were considered distinct because they are under different hydrologic regimes and many are separated by levees. These small patches vary in water depths, hydroperiod, vegetative community composition and, potentially, food availability at any given time. Water Conservation Area (WCA) 3A should probably be further subdivided because the area north of Interstate 75 is very different in these aspects from the area south of I-75. Even within southern WCA 3A, the northern habitat differs from the habitat in the ponded area to the south, near Highway 41/Tamiami Trail.

The peripheral areas are wetlands anywhere in the state that are not within the five aforementioned major wetland regions. These include small lakes, agricultural fields and canals, urban areas (probably retention ponds), and small ephemeral wetlands.

Radio Location Data Collection

Juvenile birds in 1992-1995 and 2003-2006 were equipped with radio-transmitters at the nest at the time of fledging (~28 days). The radio-transmitters were attached to the bird via a Teflon harness. The harness was constructed with four pieces of Teflon strap held together with degradable thread and designed to fall apart and away from the bird in two years (approximately the same lifespan as the battery in the transmitter).

In the time period of 1992-1995, data on bird locations was collected at approximately 14-day intervals. To make this data more comparable to the later data collection period, the locations from the second half of each month were excluded from the analysis. In both eras of data collection, the entirety of the snail kite's range was covered, from Everglades National Park in southern Florida to Lake Tohopekaliga to the north.

During 2003-2006 aerial surveys were conducted once per month, in a block of four to five consecutive days. Before each survey half of all radio frequencies were stored in one receiver and the other half in a second receiver. Bracketing to allow for drift did not occur because every frequency was audible at 1 to 2 KHz below and above the last known best signal. There was one small two-element antenna attached to each wing, and the aircraft traveled at approximately 1370 meters above ground level whenever possible. At this height most signals were detectable at a distance of 24 km and some up to 32 km.

Transects across major wetlands were flown at about 145 km per hour indicated airspeed (ground speed ranged from about 113 to 177 km per hour, depending on speed and direction of the wind relative to our flight path). Each transect was about 12 km away from the previous transect. The perimeters of large lakes (≥ 5000 ha.) were encircled and small lakes (< 3000 ha.) were bisected. When flying over areas that were not considered likely to be used by kites

(e.g. urban areas), our speed increased to no more than 177 km per hour and/or the transects were flown farther apart.

The observer in the front seat used a handheld GPS receiver to record the survey tracks. Each radio receiver was set to scan through its set of frequencies, switching to the next frequency every 4 seconds, and the gain was turned up to the maximum for greatest sensitivity to weak signals (loudness in the observer's headphones was adjusted with the volume control). Both antennae were used at all times while scanning in order to hear signals from all directions.

The front receiver was stopped from scanning when a signal was heard; each antenna was turned off in sequence to determine the general direction to the signal. Then the signal was boxed in by flying a progressively-smaller square pattern around the signal. This meant the airplane was as close to the bird as possible, and the GPS location was recorded. During this tracking process, it was also determined if the signal had drifted to a new frequency. If so, the new frequency was recorded. When the back receiver detected a signal, the front observer was notified and the signal was tracked in the same manner described above, while the back receiver continued scanning the other frequencies. After a signal was tracked down, the plane returned to the previously abandoned transect, both antennae were selected, and both receivers were set back to scan.

Data Analysis

Maximum likelihood estimation

Maximum likelihood is an estimation procedure to determine the parameters that maximize the likelihood of the data. It uses data-based deductions about structural features of a distribution: given an observed value of \underline{x} , the researcher is looking for the corresponding value of the distribution's parameter θ (Williams et al., 2002). The data, \underline{x} , is known, as it has been

obtained by sampling the population, but θ is unknown (Williams et al., 2002). $\hat{\theta}$ is the estimation of parameter θ ascertained from the known sample \underline{x} and its distribution (Williams et al., 2002). $\hat{\theta}$ is based on the random variable \underline{x} , and therefore is also a random variable, so it has its own distribution inherited from $f(\underline{x}|\theta)$ (Williams et al., 2002).

One estimates θ by sampling the population and using the distribution function $f(\underline{x}|\theta)$ as a likelihood function (Williams et al., 2002). The likelihood function is expressed as $L(\theta|\underline{x})$, and the log likelihood must be differentiated with respect to θ and set equal to 0 to determine the maximum likelihood estimate of θ ($\hat{\theta}$) (Equation 3-1) (Williams et al., 2002).

$$\frac{d[\log L(\theta | \underline{x})]}{d\theta} = 0 \quad (3-1)$$

In the case in which there are k parameters in $\underline{\theta}$, then k likelihood equations are defined by partial differentiation of the log likelihood with respect to each parameter (Equation 3-2) (Williams et al., 2002).

$$\frac{\partial[\log L(\underline{\theta} | \underline{x})]}{\partial \theta_i} = 0, i = 1, \dots, k \quad (3-2)$$

Simultaneous solution of the likelihood equations yields the vector $\hat{\underline{\theta}}$ of maximum likelihood estimates for $\underline{\theta}$ (Williams et al., 2002).

Multistate models

Likelihood-based multi-state models were used in MARK (White and Burnham, 1999) to model the probabilities of movement within and among the different wetland units. The multi-state model (Lebreton and Pradel, 2002, White et al., 2006, Hestbeck et al., 1991, Williams et al., 2002) an extension of the standard Cormack-Jolly-Seber (CJS) live recapture model to multiple states or strata, simultaneously estimates probabilities of movement (ψ), apparent survival (S)

and detection probabilities (p). ψ_i^{ab} is defined as the probability that an individual in location a at time t_i was in location b at time t_{i+1} given that it was alive at t_{i+1} . S_i^a is defined as the probability for an individual alive in location a at time t_i to survive between time t_i and t_{i+1} . p_{i+1}^b is defined as the probability of recapture of an individual that was alive and associated with location b at time t_{i+1} . MARK uses linear logistic models as the basis for a range of multistate models that can be fit by using maximum likelihood estimation (White et al., 2006, Lebreton and Pradel, 2002). Once the likelihoods are maximized, MARK constrains the sum of all movement probabilities out of a stratum to be ≤ 1 . It then takes the sum of these probabilities and subtracts it from 1 in order to derive the probability of remaining in a stratum. In order to enforce this constraint, multinomial logit (mlogit) link functions were used in program MARK.

As multistate models have a multimodal likelihood surface, it is suggested that alternate optimization methods be used any time there are greater than two states (Cooch and White, 2007, Ellison et al., 2007). Simulated annealing is a stochastic global optimizer (Bolker, 2008) that evaluates the likelihood functions many more times than the more frequently used less intensive algorithm (White et al., 2006). Simulated annealing will randomly jump from a point on the likelihood surface to a different set of parameter values that comprises a new point on the surface (White et al., 2006, Bolker, 2008). This is done so that the algorithm does not get stuck on one of possibly numerous local maxima but will instead be more likely to find the global maximum (Goffe et al., 1994, Lebreton and Pradel, 2002).

The assumptions for this model are based on Brownie et al. (1993). The most important assumption for this model is that all mortality takes place before movement. It assumes that individuals do not die during transition or while in a new state before they are detected on the next encounter (White et al., 2006). Because of this assumption, estimating stratum-specific S

parameters can be problematic especially when the strata are geographic states (White et al., 2006). In order to avoid this problem, and because battery life in the radio transmitters would be reflected in the S parameters, survival was treated as a nuisance parameter that estimates a combination of survival of the radio-transmitters and apparent survival of the birds.

Radio-transmitters and detection probability

The detection probability of radio-tagged individuals is affected by many factors. The signal from the transmitter can be blocked or reflected by physical objects in the environment (Meyer). A flying/foraging snail kite should be more detectable than a perched snail kite, especially one under the cover of tree foliage or grasses. The bird's feathers and body can impede transmission if the antenna is improperly positioned during tagging. Similarly, wet foliage or plumage touching the antenna can reduce power output and, thus, detection range.

Several characteristics of the radio signal affect the probability of detection. A longer pulse and a higher pulse rate (singly or combined) increase detectability (Meyer). The frequency also affects detection, with higher frequencies being more likely to reflect and be scattered in the environment than lower frequencies due to their shorter wavelengths (Meyer). Power output is also a factor. If the transmitter is designed with a strong signal, it will be more detectable than one with a lower power output (Meyer). However, stronger transmitters drain their batteries faster, so signal strength is often reduced to increase transmitter life.

The method of data collection can cause detectability issues. A signal is more detectable when the scanning receiver is set to linger longer on each frequency. Frequencies of radio-transmitters also tend to drift from the factory-set frequency. They usually drift downward, but the direction is not consistent (Meyer). If an observer is unaware of this possibility and doesn't search for a stronger signal other than the factory assigned number, detection suffers. The type of antenna used during flights also will affect detection. Small, two-element designs detect

fainter signals (i.e., are more sensitive) than multi-element models, but they cannot pinpoint a signal as well (i.e., are less selective) (Meyer).

To take into account as many detection problems as possible, I set p to be different in the two time periods (pre- and post- habitat degradation) and within those two eras, to be different region by region. This should take into account the difference in radios used in the two studies and the difference in detection due to varying collection methods in the different strata (e.g. in West Palm Beach we were allowed sometimes to only fly once over because of air traffic near the Palm Beach International Airport).

Multiple multistate models for multiple spatial scales

Wetland isolation is categorized as contiguous (cw), moderately isolated (mw), and isolated (iw). Contiguous wetlands (separated by small barriers) are located in region E; moderately isolated wetlands are located in region K; each of the five regions is considered to be isolated from the other (Bennetts et al., 1999, Martin et al., 2006) (Figure 2-1). Three analyses were conducted to resolve large-scale movement versus smaller-scale movements at the three levels of isolation. The first analysis estimated movements between the five isolated major wetland regions and the periphery. The second analysis estimated movement within the Kissimmee Chain of Lakes region between the moderately isolated lakes. The third analysis estimated movement within the Everglades region between the contiguous wetlands comprising that region.

Parameter index matrices and design matrices

Measures of habitat configuration as covariates: The same measures of habitat configuration of Martin et al. (2006) were used to make the post-degradation time period movement probabilities comparable to their results and to help explain degradation effects because “the effects of connection and habitat type on population dynamics [are] potentially

multiple and complex (Boudjemadi et al., 1999).” Patch size (Golden and Crist, 2000, Hovel and Lipcius, 2001) and isolation were used as measures of habitat configuration (Mossman and Waser, 2001, Rukke, 2000). To model movement among regions over the landscape, patch size covariates were used and are distinguished as such: area of donor site (AD) and area of receiving site (AR). The distance between centroids of donor and receiving regions (d) was also used as an isolation covariate. Patch area and distance can not be used to model movement within region K as the fourth category is a conglomerate of the all other lakes than East Lake Tohopekaliga (1), Lake Tohopekaliga (2), and Lake Kissimmee (3). Wetlands WCAs 1 (4), 2A (5), and 2B (6) were combined to form one wetland, and wetlands WCA 3B (8) and Everglades National Park (ENP) (9) were combined to form one wetland, while WCA 3A and Big Cypress National Preserve both remained as distinct wetlands to model movement within E. Wetlands were combined because a seven-site model requires more data than I had. Combining ENP and WCA 3B was intuitive as these wetlands contain remnants of Northeast Shark Slough and have similar hydrology. The preceding covariates were tested in my model set by the use of the design matrix. The design matrix allows me to model movement estimates as functions of biologically relevant measures such as habitat configuration (White et al., 2006).

Seasonal models: One additional covariate also used by Martin et al. (2006) and Bennetts and Kitchens (2000) to estimate movement within regions E and K was a seasonal effect (seas) delineated into three 4-month seasons (January-April, May-August, September-December). By grouping capture and recapture occasions by season, the predictability of this factor on movements was tested through the use of the parameter index matrices. A multiplicative effect of covariates is shown with (*) and an additive effect is shown with (+).

Age models: When looking at between year survival, Bennetts et al. (1999) found that birds younger than 1 year had a lower annual survival than birds greater than 1 year old. When exploring within year survival, Bennetts and Kitchens (1999) found that after 4 months of age, young birds had survivorship similar to adult birds. An age effect on movement probability was tested for each era. In the pre-degradation high-quality habitat, movements were modeled to be different between birds that were four months of age and younger and birds five months of age and older. In the post-degradation low-quality habitat, movements were modeled to be different between birds that were 12 months of age and younger and birds thirteen months of age and older. Models were built to test different movements between age at all spatial scales by manipulating the parameter indices via the parameter index matrices.

Modeling the nuisance parameter S was slightly more complicated as it was a combination of apparent bird survival and radio transmitter life. In the first era, the average transmitter life was nine months, and in the second era, the average transmitter life was 22 months. So, in the first era, survival was modeled to be different between birds that were four months of age and younger, birds five months of age through nine months of age, and birds 10 months of age and older. In the second era, survival was modeled to be different between birds that were 12 months of age and younger, birds 13 months of age through 22 months of age, and birds 23 months of age and older.

Effect of covariates on movement: I modeled movement probabilities as linear-logistic functions of my covariates (Equation 3-3) (Blums et al., 2003, Martin et al., 2006) where β_i and β_{AR} are the parameters I estimated when finding the probabilities of moving from one patch to another as a function of receiving site area. β_i is the intercept and β_{AR} is the slope for the area of receiving site. The probability of moving is positively related to the area of the receiving site.

$$\text{logit}(\psi(AR)) = \beta_i + \beta_{AR} \quad (3-3)$$

Model selection

We used the Akaike Information Criterion (AIC) (Burnham and Anderson, 2002) to select the most parsimonious model (i.e., the model that provides the best compromise between bias and precision) from all candidate models. According to this criterion, models with lower AIC values are better supported by the data. The AIC rewards a model for having a low negative log-likelihood, and penalizes the model for each parameter. I used AICc which accounts for small samples. Models that have a delta (difference) AICc of < 2 , were considered as good as the most parsimonious model. The weight (w) (Burnham and Anderson, 2002) of the model is another measure that I used to choose the best model.

Effect size

After selecting the most parsimonious model which showed a difference in movement between the two eras, I needed to answer the following question: how big is the difference? The estimated effect size and its confidence interval contained the true effect size and helped me understand the biological significance of the difference in the movement estimates (Cooch and White, 2007). If the 95% confidence interval of the effect size did not overlap zero, there was a statistically significant difference between the two estimates.

Results

Connectivity

The average monthly movement between the contiguous wetland units within region E in the pre-degradation era was 0.071 (95% CI = 0.054 to 0.088), and in the post degradation era, it was 0.104 (95% CI = 0.091 to 0.117). The average monthly movement between the moderately isolated lakes within region K was 0.048 (95% CI = 0.032 to 0.065) and did not differ between eras. The average monthly movement out of region E in the pre-degradation era was 0.005 (95% CI = 0.001 to 0.008), and in the post-degradation era, it was 0.022 (95% CI = 0.017 to 0.027). The average monthly movement out of region K in the pre-degradation era was 0.012 (95% CI = 0.003 to 0.022) and in the post-degradation era, it was 0.023 (95% CI = 0.013 to 0.033). The average monthly movement between the five isolated wetland regions was 0.007 (95% CI = 0.002 to 0.011) pre-degradation and 0.046 (95% CI = 0.038 to 0.055) post-degradation.

Average monthly movement was greater among contiguous wetlands than among isolated wetland regions within the same era, while movement was greater between contiguous wetlands than between moderately isolated wetlands only during the post-degradation era. Movements were higher among moderately isolated wetlands than among isolated regions in the pre-degradation era, and movements among the moderately isolated wetlands and the isolated wetland regions did not differ in the post-degradation time period (Figure 3-3).

Average monthly movements were greater within than out of the wetland region E during both eras. Average monthly movements were greater within than out of wetland region K during the pre-degradation era, but were not significantly greater within than out of the wetland region in the post-degradation era (Figure 3-4).

Fragmentation

Movement in region E was affected by fragmentation. The top model of movement in region E held 99% of the weight: $S[b(r^{*0-4,5-9,10+})a(r^{*0-12,13-22,23+})] p[b(r)a(r)] \psi[b(AD)a(r)]$ (Table 3-1). The area of the site from which the birds moved was a strong predictor of movement. In fact, opposite from what was expected, the movement estimates increased as size of the donor site increased ($\hat{\beta}_{AD} = 0.0442597$, 95% CI = 0.019197 to 0.069323).

During the post-degradation time period in region E, the movement estimates were not affected by any specific fragmentation measure. Neither era's movements within region E agreed with my prediction that movement probabilities of juveniles should decrease with increasing size of the donor site or that movement should increase with increasing size of the receiving site.

Fragmentation measures could not be used when modeling movement within region K due to the fourth stratum being a conglomeration of all the remaining small (< 3000 ha.) lakes in the region (Martin et al., 2006). The best predictor of movement in region K was seasonality; 60% of the model weight is on models including this covariate (Table 3-2), but the effect sizes between seasonal movement in the top three seasonal models showed that movements differed significantly only in May through August and September through December (ESs = 0.00016, 95% CIs = 0.0069 to 0.0751, 0.0087 to 0.0762, and 0.0085 to 0.0761) (Figure 3-5).

Movement among regions was affected by fragmentation. The top model held 95% of the weight ($S[b(.)a(.)] p[b(r)a(r)] \psi[b(AR+d)a(r)]$), (Table 3-3), indicating that the area of the site to which the birds moved and the distance between sites were predictors of movement, but only in the pre-degradation era. The probability of movement increased as the area of the receiving

site increased. The relationship was very strong ($\hat{\beta}_{AR} = 0.235566$, 95% CI = 0.1034969 to 0.3676352) There was no relationship between distance and movement between locations ($\hat{\beta}_d = -0.0048537$, 95% CI = -0.0158929 to 0.0061855). A model without distance would probably fit the data better, but was not part of the a priori set.

Habitat Degradation: High-Quality vs. Low-Quality Eras

Monthly movement between the wetland units in region E differed in certain wetland units between the two eras (Figure 3-6). Movement from most areas increased in the post-degradation era (Figure 3-7). Eight of 12 movement estimates from wetland units increased and five were significant (Figure 3-8). Movements from WCA 3A to ENP/3B (ES = 0.052, 95% CI = 0.019 to 0.085), WCA 3A to BICY (ES = 0.064, 95% CI = 0.020 to 0.108), ENP to WCA/3A (ES = 0.248, 95% CI = 0.150 to 0.347), BICY to WCA 3A (ES = 0.084, 95% CI = 0.008 to 0.159), and WCA 1/2 to WCA 3A (ES = 0.093, 95% CI = 0.019 to 0.168) all increased significantly. Movements towards Water Conservations Areas 1 and 2 decreased significantly from all of the other strata (Figures 3-7 and 3-8).

Movement between the lakes in region K did not differ between eras (Table 3-2). The top seven models held 75% of the weight, and all seven showed no difference in the movements pre- and post degradation (Figure 3-9). When considering all models in the model set, 90% of the weight was on models that showed no difference in pre- and post-degradation movements.

Over the snail kite's entire range, movements among the five major wetland regions differed between the two eras (Figures 3-10 and 3-11). Movement increased from most areas in the post-degradation era (Figure 3-11). Eighteen out of twenty movement estimates from wetland regions increased and six of those were significant (Figure 3-12). Movements from E to Okeechobee (O) (ES = 0.0271, 95% CI = 0.0132 to 0.0409), E to Loxahatchee Slough (L) (ES =

0.0573, 95% CI = 0.0335 to 0.0811), O to E (ES = 0.2959, 95% CI = 0.1679 to 0.4239), O to L (ES = 0.1158, 95% CI = 0.0084 to 0.2232), L to E (ES = 0.0780, 95% = 0.0232 to 0.1327), K to L (ES = 0.0497, 95% CI = 0.0056 to 0.0938) have all increased significantly. Two out of five movement estimates from the major regions into the periphery have increased (Figure 3-11), neither of which is significant (Figure 3-12).

Habitat Quality and Fragmentation

Movement between regions K and E appeared to increase, although the change was not significant (Figure 3-12). Movement from region K to region E (ES = 0.008, 95% CI = -0.020 to 0.036) increased more than from region E to region K (ES = 0.001, 95% CI = -0.003 to 0.006).

Age and Sex-Biased Movements

There was very little evidence that movements varied by age or sex within regions K and E. Within region E, the only model with any support of movement varying by age had a weight 0.0001, and the only model with any support of movement varying between females and males had a weight of 0.0003. Within region K, the models with any support of movement varying by age had a combined weight of 0.2603 (Table 3-2). When I added sex to the top model of movement within K by season, weight was only 0.020.

There is no evidence that movement on the larger spatial scale was affected. During both eras, age was not a factor in predicting movement probability. The only model that received any support of a difference in movement between ages had a weight of 0.00783. This model also had numerical convergence problems and could not be considered reliable. As I only had information for the sex of the birds in the post-degradation era, I tested the sex effect on movements only during this era. Sex had no effect on movement (model weight is 0).

Discussion

The Florida snail kite population is known to be highly mobile and nomadic. Individuals of the population have historically been able to escape the physiological strain imposed upon them by any reduction in forage base (historically caused by drought) by simply moving to a concurrently unaffected wetland (Bennetts and Kitchens, 1997b, Bennetts, 1993, Bennetts and Kitchens, 1997a, Beissinger and Takekawa, 1983). The population has become increasingly distressed after the 2001 precipitous decline in numbers, and growth rate has been low in the post-habitat degradation state of the Everglades ecosystem. Adult survival declined; nesting and fledging declined; juvenile survival and subsequent recruitment declined, and movements increased overall. Individuals were not able to simply move to a different wetland to satisfy their foraging requirements when one becomes inefficient for foraging; they were forced to move again upon arrival. The snail kite population during the pre-degradation era was probably at the “low-risk exploration” point on the conceptual relationship between dispersal and food availability presented by Bennetts and Kitchens (2000) (Figure 1-2), whereas the population during the post-degradation era was probably at the “leave or starve” point on the same relationship. Some of the movements in the post-degradation era were not higher than pre-degradation. This situation could have occurred due to a “high-risk for marginal benefits” (Bennetts and Kitchens, 2000). It is probable that some wetland regions are in a greater state of degradation than others, and kites are forced to move from those regions due to lack of forage base, while other regions, even in a degraded state can still support foraging to some degree. The higher movement rates that this study exhibits contribute to the body of evidence that the system is degrading and has caused the population to respond differently after its 2001 decline than it had pre-decline.

Connectivity

We predicted that monthly movements within regions would be greater than monthly movements among regions. This was true in both eras especially when comparing average movement within the contiguous wetlands of region E and average movement from region E to the four other major regions and the periphery. I would expect that, as the Everglades is the largest and most connected area of snail kite habitat in the state, birds should be able to find foraging opportunities somewhere in the region without having to venture into and across the unpredictable and unnatural landscape of the matrix. I also found that average monthly movement among all five isolated major regions was lower than average monthly movement within the contiguous E region. I also expected that snail kites would be less able to move between islands of habitats that are surrounded by a mostly unusable matrix of urban areas and agricultural fields.

It is fairly clear that average monthly movement was greater within region K than out of the region to the four other major regions and the periphery. The overlap in confidence intervals, when comparing movement within region K to movement out of the region in the post-degradation era, is very small (0.001). Average monthly movement among the moderately isolated lakes of region K was not so clearly different than monthly movement on the contiguous and isolated levels of connectivity; movements among the moderately isolated lakes were not different from average movements among the contiguous wetlands pre-degradation or average movements among the isolated regions post-degradation. This could be because the movement within region K was not different in the two eras. If differences could be found by era, then I may be more easily able to tease out changes in movement across levels of connectivity within the same era.

Fragmentation

According to island biogeography and meta-population theory, movement should be greater between two areas that are closer in distance than two areas that are farther away from each other (Schtickzelle and Baguette, 2003, Hanski, 2001). Movement should be greater toward the larger of two habitat islands, and movement should be greater away from the smaller of the two habitat islands. Presumably, the closer and larger an island, the more likely an organism will be able to find it when moving. It is also reasonable to think of a smaller patch of habitat island either running out of resources or becoming overcrowded before a larger patch and therefore increasing the probability of organisms moving away from the smaller patch.

None of the aforementioned predictions were confirmed by analysis when modeling movement within region E. The area of the site from which the birds left did have an effect on movement but in the opposite manner and for only one era. It is possible that the manner in which I assigned fragmentation descriptors for the wetlands in the Everglades is false due to the high level of connectivity. As it is true that the Everglades are highly fragmented by man-made structures of levees and canals, these structures must not impose size limitations on the wetlands. As these structure impose more of a hydrologic constraint on wetland functions, it may be more appropriate to model movement as a function of one or more hydrologic variables.

When modeling movement over the snail kite's range among the isolated regions, one fragmentation covariate stands out as being a strong predictor. The area of the site to which the birds moved strongly influenced the probability of movement in the pre-degradation era, as predicted. However, in the post-degradation era, no fragmentation measures were found to be predictors of movement. This could be an indication that the birds were not finding suitable foraging in these "large" islands of "habitat" any longer and may not have been experiencing the

islands the same way that they had in the past. I continue to call these regions wetlands, but they may not have the necessary vegetative communities to meet the foraging needs of the snail kite.

I produced slightly different estimates of movements of juveniles in the pre-degradation era than did Martin et al. (2006). Their analysis showed a strong negative relationship between distance and probability of movement, no relationship with the area of receiving site and probability of movement, and only a slight positive relationship between the interaction of the two aforementioned factors and the probability of movement. The discrepancy probably has a number of causes. First is the reduced number of encounters in this analysis. As the encounters from the later half of the months from the pre-degradation era were removed to make the data sets from both eras comparable, a few recapture occasions were lost and instead were replaced with zeros. This approach probably rendered detectability slightly lower, but this was taken into account as detection was modeled. Second, as it was likely that the nuisance parameter of survival (a combination of radio life and bird apparent survival), and the parameter of detectability differed between studies due to an altered ecosystem and possible differences in data collection, the models estimated S and p rather than setting them equal to 1 (a method to isolate ψ). (See Appendix A for estimates.) Third, Martin et al. (2006) also analyzed the pre-degradation movements alone, while this study compared the eras. The effect would be similar to that produced when Martin et al. (2006) showed differences in the top models when analyzing the adults and juveniles together to be able to compare them versus analyzing the juvenile movements alone.

Habitat Degradation: High-Quality vs. Low-Quality Eras

Bennetts and Kitchens (2000) found no evidence of movement due to seasonally low food availability while Beissinger and Takekawa (1983) and Takekawa and Beissinger (1989) showed high levels of movement in response to extremely low food availability. The Bennetts and

Kitchens (2000) study was during a period of relatively low food stress, while the Beissinger and Takekawa (1983) and Takekawa and Beissinger (1989) studies were done during extreme drought. The pre-degradation movement probabilities correspond to the Bennetts and Kitchens (2000) study (in fact, it used the same data set), while the post-degradation probabilities correspond to the Beissinger and Takekawa (1983) and Takekawa and Beissinger (1989) studies.

The sum of monthly movements from all wetlands increased in the low-quality post-degradation era. Water Conservation Area 3A (3A) in the Everglades region, which is the largest wetland unit, produces the most young and is the most important area for foraging birds (Martin et al., 2007a). This wetland, however, is considered extremely degraded (Kitchens et al., 2002, Ogden, 2005, Martin et al., 2007a, Zweig, 2008). The increase in the sum of monthly movements out of 3A closely approached significance with only a very small overlap (0.0004) of confidence intervals. Among the pair-wise movement estimates, all of the significant increases in movement involved 3A. Perhaps movements into 3A were exploratory, and movements out of 3A were due to lack of forage base (Boudjemadi et al., 1999). Everglades National Park and Water Conservation Area 3B (ENP/3B) also have been highly-foraged wetland units. The sum of monthly movements out of this area increased significantly in the post-degradation era.

Among-region movement increased post-degradation. Total movements away from the Everglades, Lake Okeechobee, and the Kissimmee Chain of Lakes all increased. The sums of the movements from the Everglades and Lake Okeechobee were significant and probably the most worth noting, perhaps because these two regions are the largest in area, and historically were the most important habitat for the snail kite species (Sykes, 1979, Beissinger and Takekawa, 1983). This situation could be detrimental if organisms continue to move away from these regions in search for food elsewhere. Based on pair-wise movement estimates, movement

from each of these two regions to the other increased significantly. This begs the question: are birds traveling back and forth looking for food with no other known habitat to forage?

Movements toward Loxahatchee Slough from the Everglades, Lake Okeechobee, and the Kissimmee Chain of Lakes have increased significantly. Loxahatchee Slough is the smallest wetland region and is in close proximity to an unfavorable urban environment. This trend of movement to the very small isolated region can cause a depression in the availability of food resources due to increased competition (Lenihan et al., 2001) in the region. The population will not sustain itself in such a small area.

I made a prediction that seemingly contradicted island biogeography: movement into the periphery would increase in the post-degradation era. I predicted that the low-quality state of the system may have changed how the species utilizes the ephemeral and unfavorable matrix. However, I determined that monthly movement into the periphery (matrix) from the major regions did not increase significantly. The population did appear to move among the isolated regions and into the matrix less than among the more connected wetland units and lakes within regions.

Habitat Quality and Fragmentation

We predicted that movement between the two most distant regions K and E would decrease in the post-degradation era due to a lack of functional stepping stones. This was not the case, however. As distance did not play a role in determining the probability of moving between two areas, the practical increase in linear distance between the Everglades and the Kissimmee Chain of Lakes did not have a negative effect on movement. In fact, in accordance with my prediction that overall movement increased post-degradation, both movement estimates appeared to increase, although not insignificantly.

Age and Sex-Biased Movements

Neither the age nor sex of an individual had any bearing on how it moved across the landscape. Females did not move more than males, males did not move more than females, and young birds did not move more than more experienced older birds on any spatial scale. As these individuals were monitored for no longer than the first 22 months of their lives, possible sex and age differences in movements may not yet have appeared yet. There may be a difference as birds gain years of experience with the landscape. This will have to be determined with a different data set.

The lack of sex and age differences may have been due to the fact that the population is in distress and is moving at a higher probability. Perhaps all groups were affected by low food levels and had to forage continuously. There are social aspects that are not known about the snail kite, such as if young birds are following adults to understand the landscape and get help feeding. These questions may not be answerable for the currently declining population that has experienced increased movement probabilities and suffers low survival and reproduction, but may be very important to understand how to maintain a stable and then growing population once it again becomes so.

Natal Area Implications for Movement

As snail kites have exhibited natal philopatry (Martin et al., 2007c), there may be evidence of natal area influencing where a juvenile will move after its original dispersal from its natal wetland. Martin et al. (2007c) found that juvenile snail kites are more likely to return to their natal areas rather than disperse to a new, previously unexplored wetland. They also found that snail kites tended to stay in their natal areas more than non-natal areas. It would be very interesting to see how natal philopatry is still exhibited in the degraded system. Perhaps during the large drying event in the Everglades region in 2004, the individuals born there would not be

able to disperse to the refugia habitats (e.g. Kissimmee Chain of Lakes) as easily as those individuals born in the refugia would be able to return post natal dispersal. Movement and survival for birds whose natal region experiences the drought should be lower than the others. However, I did not include this in my analysis. Adding this variable may stretch the data beyond its predictability limits and natal area may not show up as a significant predictor of movement.

Conclusions and Conservation Implications

Other studies that compared transition rates between low- and high-quality patches and found that low habitat quality was associated with higher transition probabilities to and from geographic areas (Pettorelli et al., 2003, Lenihan et al., 2001, Boudjemadi et al., 1999, Senar et al., 2002, McPeck and Holt, 1992). They also found that movements (for certain groups in a population: Pettorelli et al., 2003: juvenile roe deer; Lenihan et al., 2001: fishes; Boudjemadi et al., 1999: juvenile common lizard; Senar et al., 2002: juvenile citril finch) occurred at a higher rate from the low-quality habitats towards high-quality habitats. Habitat quality in many of the studies was determined by food availability. I defined quality in the same manner, but I considered differences in quality across time, whereas many studies did so with regard to space. I also found increased movement when habitat quality was low as compared to when habitat quality was high. In addition, I compared movement between areas, and certainly the different regions and wetlands and lakes within regions must have varied according to habitat quality. The size of the wetland regions can be viewed as a measure of quality; other measures include hydrologic conditions, vegetative community composition and food availability, and these should be considered in a future study.

The increased rate of movement that I documented in the post-degradation state of the system could cause a great physiological strain on individuals (Orians and Wittenberger, 1991, Kauffman et al., 2004) and may affect their reproduction (Martin et al., 2007b) and survival (Ims

and Hjermmann, 2001, Martin et al., 2007b). Juvenile survival was especially low in the post-degradation era (Martin et al., 2006, Cattau et al., 2007). Recruitment is directly affected by juvenile survivals. Since these data have been collected and analyzed, the snail kite population has declined yet again. The population estimate for 2008 is 685 (95% CI = 611 to 759) (unpublished data).

The snail kite population in Florida is endangered and declining in numbers. The individuals in the population must be able to forage successfully, survive and reproduce. Their future offspring must also be able to carry out these most basic life functions. The current population must not simply sustain its numbers; it must increase.

Snail kites have been described as a plastic species in that they can take advantage of their ability to find refuge habitats when food resources are low, and the population can rebound from low survival due to temporal heterogeneity in habitat quality. The species however, can only “take so many hits” and can not respond with such plasticity when the habitat remains degraded. The species has had to move around the landscape at a higher rate due to this degradation of suitable habitat in order to find foraging opportunities. This higher rate of movement is probably not sustainable for a population that suffers a decline in growth rate (Martin et al., 2007b) and low juvenile survival (Martin et al., 2006). There has to be a point in which the energy lost in transition is not replaced in suspension of searching to forage.

The Everglades ecosystem is not currently able to support these population functions. All of the fragments comprising the ecosystem must be restored to a healthy, non-degraded state. The two largest fragments, Lake Okeechobee and the Everglades, must be able to support the foraging needs of much of the population instead of exporting the individuals to the smallest

fragment, Loxahatchee Slough. As it is, the ecosystem will not allow this species to exist much longer as the individuals must continue to move between fragments in order to find food.

Everglades ecosystem restoration is essential. The largest and most extensive regions of snail kite habitat have been lost due to vegetative community transition and localized apple snail population decline and perhaps extirpation (Karunaratne et al., 2006, Darby et al., 2008). Like many other species of concern which are restricted to the Everglades, this raptor is relatively long-lived, has small broods and is suffering strain on its demography. Scientists and managers must work together to restore this imperiled ecosystem and all of its inhabitants.

Recommendation for adaptive management

One feasible management recommendation would be to direct the water flow from Water Conservation Area 3A to go through WCA 3B and into Everglades National Park through Northeast Shark Slough. This should reduce ponding on the northside of Tamiami Trail and return the natural flow through the slough. The population should continue to be monitored throughout restoration efforts, and managers should respond to any negative effects that certain actions may have.

We must continue collecting data to understand how the species changes with the changing ecosystem. The Florida Cooperative Fish and Wildlife Research Unit snail kite demography and vegetative community conversion monitoring efforts must continue. The years of information already collected and the years that will be collected make up a database that makes answering the pertinent questions possible. This research effort continues to be a resource for managers. What knowledge we may have about a species' ecology may not be applicable in a different ecosystem. We must continue asking the pertinent questions and work to answer them. The organisms are responding to ecosystem degradation and we must continue to know how. The organisms will respond to ecosystem restoration and we must know how. Understanding the

population dynamics of a species is the only way we are going to be able to take the necessary actions to keep a species as a piece of the ecosystem.

Table 3-1. Movement within the Everglades region.

Model	$\Delta AICc$	w	K	Deviance
S[b(r*0-4,5-9,10+)a(r*0-12,13-22,23+)] p[b(r)a(r)] psi[b(AD)a(r)]	0	0.993	42	2818.7877
S[b(r*0-4,5-9,10+)a(r*0-12,13-22,23+)] p[b(r)a(r)] psi[b(r)a(r)]	11.08	0.004	56	2799.0815
S[b(0-4,5-9,10+)a(0-12,13-22,23+)] p[b(r)a(r)] psi[b(AD)a(r)]	12.34	0.002	28	2861.0796
S[b(0-4,5-9,10+)a(0-12,13-22,23+)] p[b(r)a(r)] psi[b(r)a(r)]	14.26	0.001	38	2841.6932

Table 3-2. Movement within the Kissimmee Chain of Lakes region.

Model	Δ AICc	w	K	Deviance
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(seas)	0	0.20	17	714.1191
S[b=a(.)]p[b(r)a(r)] psib=a(seas)	0.2738	0.17	12	725.5292
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(.)	0.7287	0.14	15	719.3516
S[b(.)a(.)]p[b(r)a(r)] psib=a(seas)	1.9136	0.08	13	724.9745
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(ages:1-4,5+)	2.1881	0.07	16	718.5674
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(ages:1-12,13+)	2.7394	0.05	16	719.1188
S[b=a(.)]p[b(r)a(r)] psib=a(ages:0-4,5+)	2.8317	0.05	11	730.2658
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib(.)a(.)	2.9176	0.05	16	719.2970
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(ages:1-4,5+*seas)	3.7867	0.03	20	711.0229
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib(seas)a(seas)	3.8171	0.03	20	711.0533
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib(.)a(seas)	4.0731	0.03	18	715.9151
S[b(.)a(.)]p[b(r)a(r)] psib=a(ages:1-4,5+)	4.357	0.02	12	729.6124
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(ages:1-4,5-12,13+)	4.4483	0.02	17	718.5674
S[b=a(.)]p[b(r)a(r)] psib=a(seas*sex)	4.4975	0.02	18	716.3394
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(seas*sex)	4.5973	0.02	23	704.7938
S[b(0-4,5-9,10+)a(0-12,13-22,23+)]p[b(r)a(r)] psib=a(ages:0-12,13+*seas)	4.7397	0.02	20	711.9759
S[b(r)a(r)]p[b(r)a(r)] psib=a(seas)	7.1698	0.01	19	716.7176
S[b(r)a(r)]p[b(r)a(r)] psib=a(.)	7.1863	0.01	17	721.3054

Table 3-3. Movement among all regions.

Model	Δ AICc	w	K	Deviance
S[b(.)a(.)] p[b(r)a(r)] psi[b(AR+d)a(r)]	0	0.95248	56	4011.29
S[b(r)a(r)] p[b(r)a(r)] psi[b(AR+d)a(r)]	6.3577	0.03965	66	3996.29
S[b(1-4,5-9,10+)a(1-12,13-22,23+)] p[b(r)a(r)] psi[b4(AR+d)b5(AR+d)a12(r)a13(r)]	9.6033	0.00783	102	3920.69
S[b(.)a(.)] p[b(r)a(r)] psi[b(r)a(r)]	20.1101	0.00004	74	3992.79

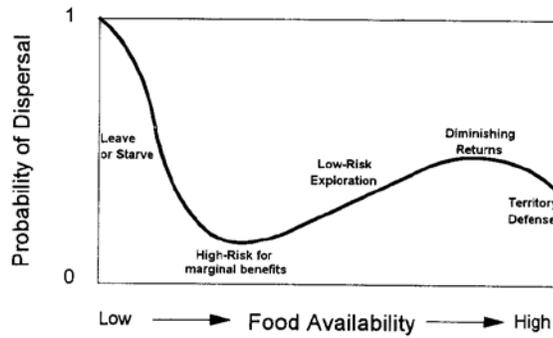


Figure 3-1. Conceptual relationship between movement probabilities of snail kites along a food-resource gradient. During periodic low-food events, animals must leave or die. At high food availability, exploratory movement, which may have high benefit during periods of localized food crunches, can be done at little risk of starvation. (adapted from Bennetts and Kitchens (2000))

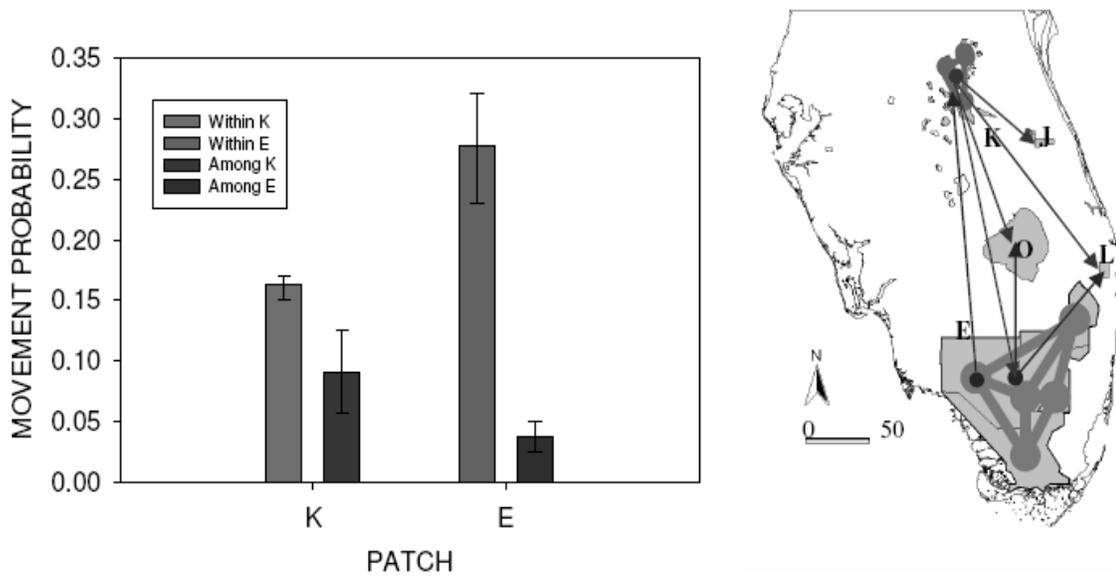


Figure 3-2. Monthly movement probabilities of adult and juvenile kites in the pre-degradation system. (adapted from Martin et al. (2007a))

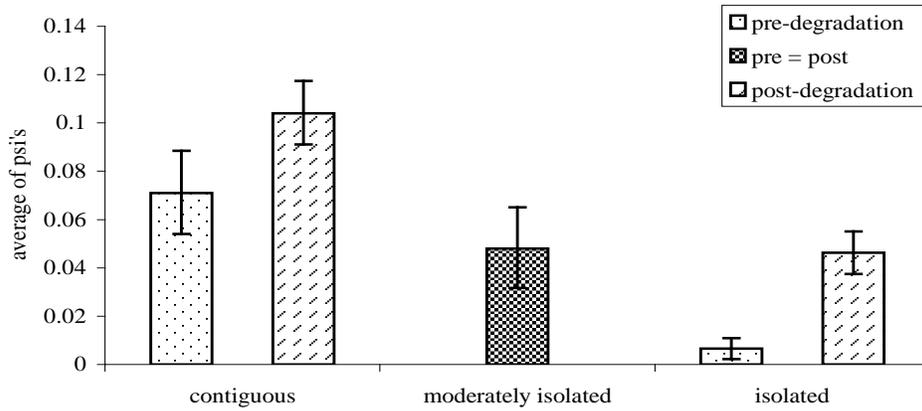


Figure 3-3. Movement across different levels of contiguity.

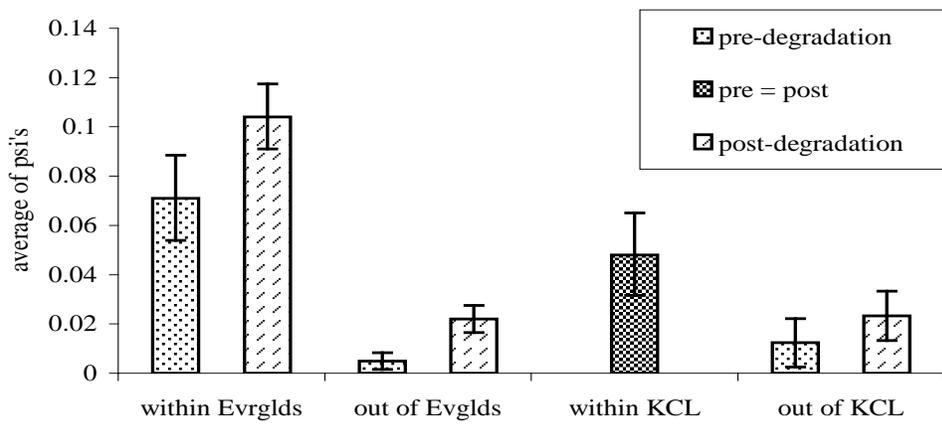


Figure 3-4. Movement within and out of major wetland regions.

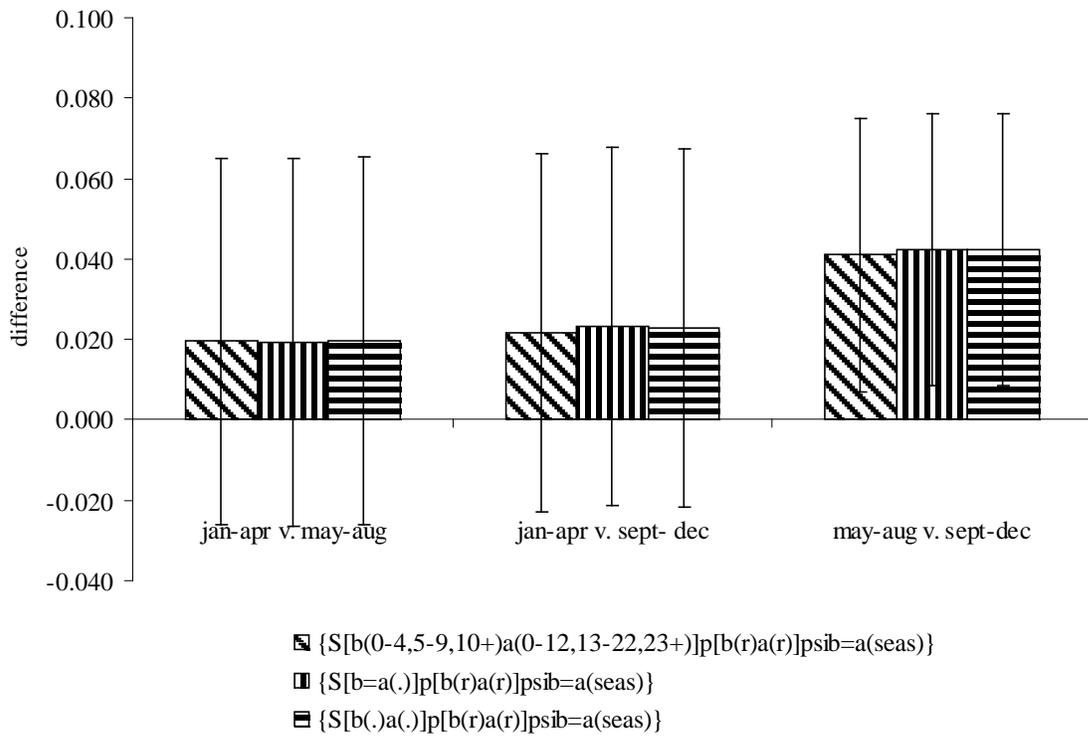


Figure 3-5. The effect size between seasonal movements in the Kissimmee Chain of Lakes.

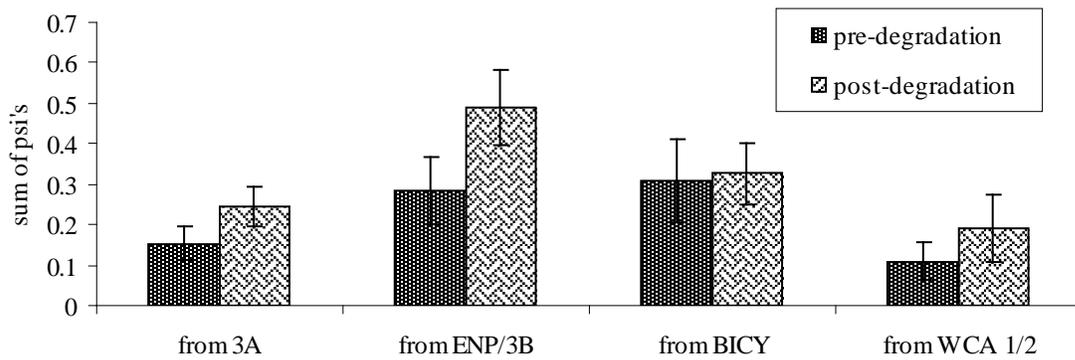


Figure 3-6. The sum of the movement probabilities from each wetland within the Everglades region.

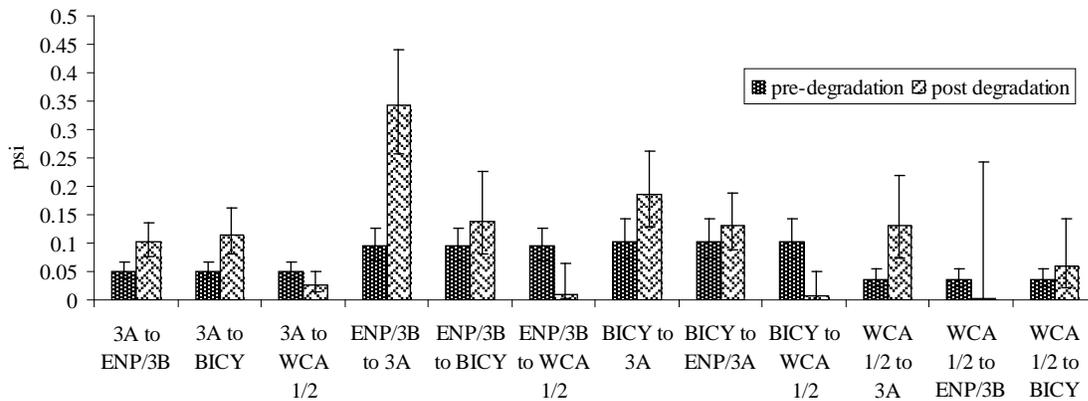


Figure 3-7. Movements within the Everglades pre-degradation vs. post-degradation.

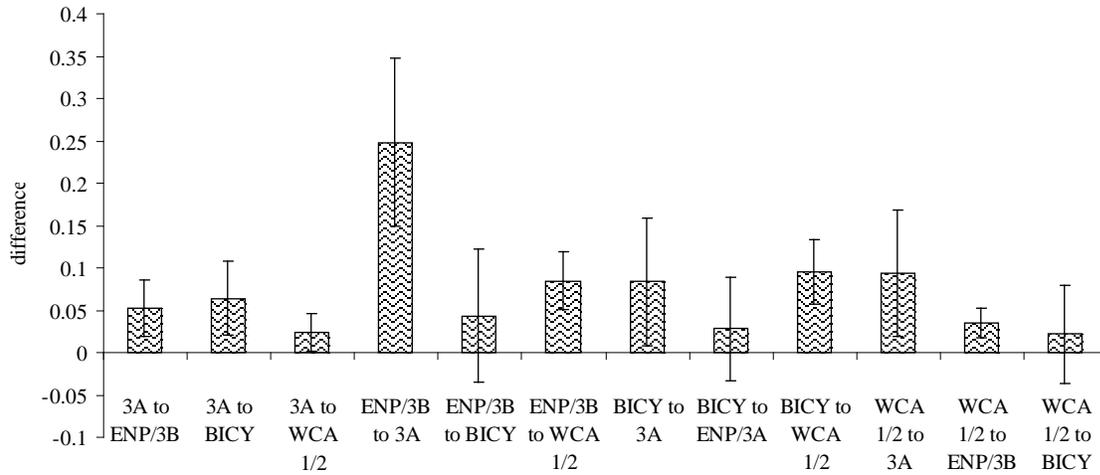


Figure 3-8. The effect size between movements in the system pre-degradation and post-degradation.

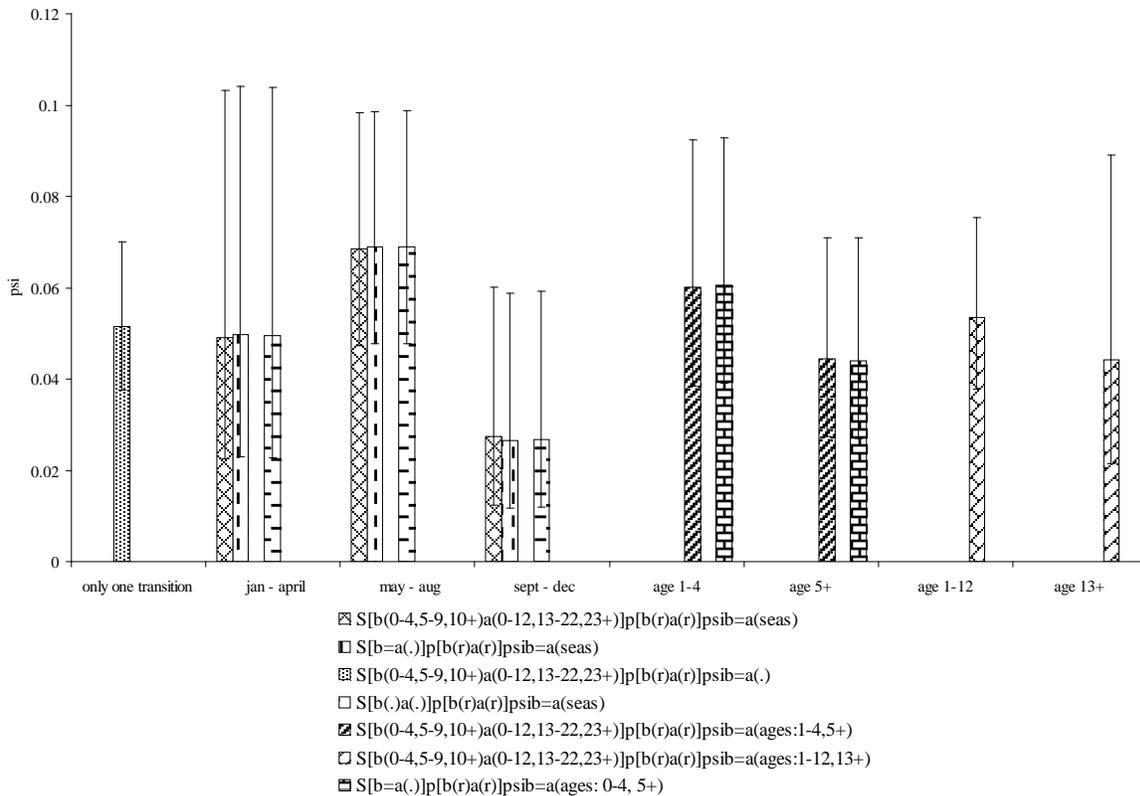


Figure 3-9. Within the Kissimmee Chain of Lakes: the top 7 models (with 75% of the weight).

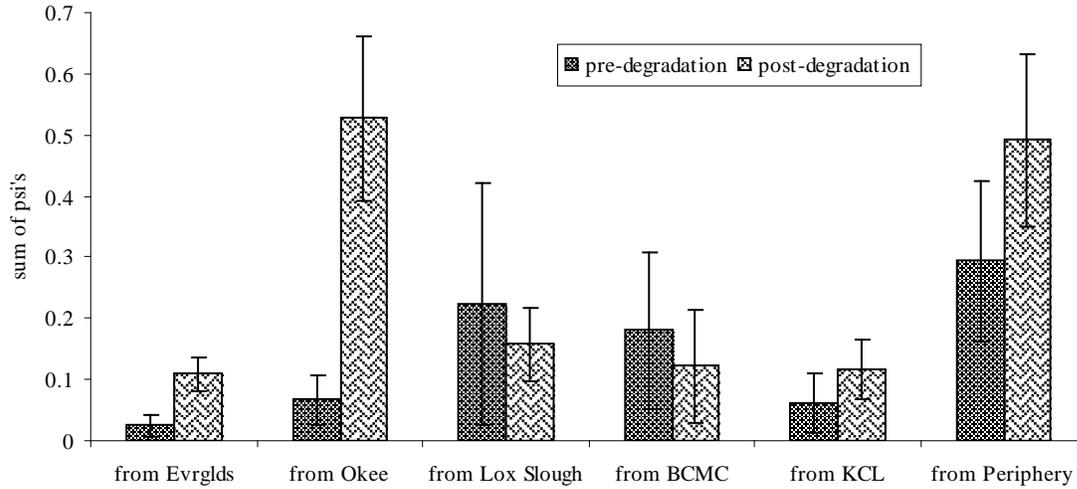


Figure 3-10. Sum of the movement probabilities from each major wetland region and the periphery.

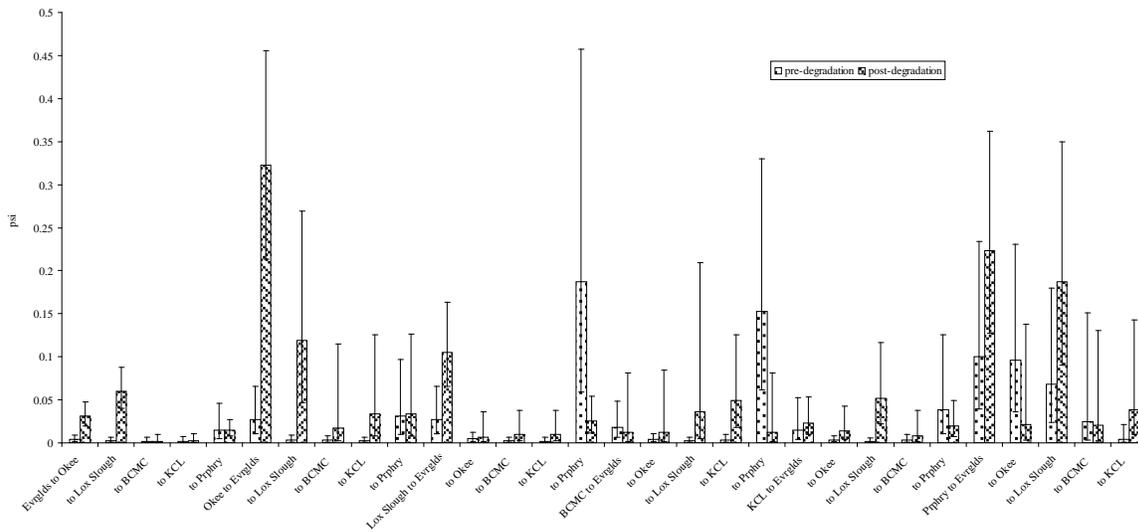


Figure 3-11. All movement probabilities among the regions and the periphery.

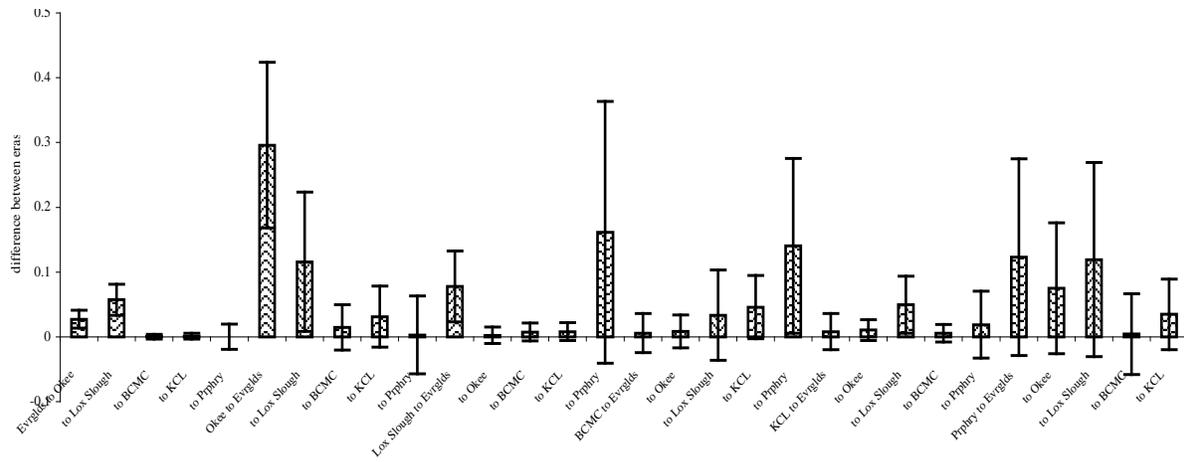


Figure 3-12. The effect size of the movement probabilities among the regions and the periphery.

APPENDIX A
SURVIVAL AND DETECTION FROM TOP MODEL OF AMONG REGION MOVEMENT

Table A-1. Estimates for survival (S) and detection (p) among all regions from the top model:
S[b(.)A(.)] P[b(r)a(r)] psi[b(AR+d)a(r)].

	pre-degradation	post-degradation
S	0.88	0.91
p for region E	0.85	0.95
p for region O	0.78	0.89
p for region L	0.92	0.05
p for region J	0.76	0.73
p for region K	0.60	0.86
p for Periphery	0.43	0.99

LIST OF REFERENCES

- Astheimer, L. B., Buttemer, W. A. & Wingfield, J. C. (1991) Interactions of Corticosterone with Feeding, Activity and Metabolism in Passerine Birds. *Ornis Scandinavica*, **23**, 355-365.
- Begon, M., Townsend, C. R. & Harper, J. L. (2006) *Ecology: from individuals to ecosystems. 4th edition*, Blackwell Publishing Ltd, Malde, Maine.
- Beissinger, S. R. (1990) Alternative Foods of a Diet Specialist, the Snail Kite. *Auk*, **107**, 327-333.
- Beissinger, S. R. (1995) Modeling Extinction in Periodic Environments - Everglades Water Levels and Snail Kite Population Viability. *Ecological Applications*, **5**, 618-631.
- Beissinger, S. R. & Takekawa, J. E. (1983) Habitat use by and dispersal of snail kites in Florida during drought conditions. *Florida Field Naturalist*, **11**, 89-106.
- Belanger, G. & Rodriguez, M. A. (2002) Local movement as a measure of habitat quality in stream salmonids. *Environmental Biology of Fishes*, **64**, 155-164.
- Belisle, M., Desrochers, A. & Fortin, M. J. (2001) Influence of forest cover on the movements of forest birds: A homing experiment. *Ecology*, **82**, 1893-1904.
- Bennetts, R. E. (1993) The snail kite, a wanderer & its habitat. *Florida Naturalist*, **66**, 12-14.
- Bennetts, R. E., Darby, P. C. & Karunaratne, L. B. (2006) Foraging patch selection by Snail Kites in response to vegetation structure and prey abundance and availability. *Waterbirds*, **29**, 88-94.
- Bennetts, R. E., Dreitz, V. J., Kitchens, W. M., Hines, J. E. & Nichols, J. D. (1999) Annual survival of Snail Kites in Florida: Radio telemetry versus capture-resighting data. *Auk*, **116**, 435-447.
- Bennetts, R. E. & Kitchens, W. M. (1997a) The Demography and Movements of Snail Kites in Florida. pp. viii, 169. USGS/Biological Resources Division, Florida Cooperative Fish & Wildlife Research Unit, University of Florida, Gainesville, Florida.
- Bennetts, R. E. & Kitchens, W. M. (1997b) Population dynamics and conservation of Snail Kites in Florida: The importance of spatial and temporal scale. *Colonial Waterbirds*, **20**, 324-329.
- Bennetts, R. E. & Kitchens, W. M. (1999) Within-year survival patterns of Snail Kites in Florida. *Journal of Field Ornithology*, **70**, 268-275.
- Bennetts, R. E. & Kitchens, W. M. (2000) Factors influencing movement probabilities of a nomadic food specialist: proximate foraging benefits or ultimate gains from exploration? *Oikos*, **91**, 459-467.

- Blums, P., Nichols, J. D., Hines, J. E., Lindberg, M. S. & Mednis, A. (2003) Estimating natal dispersal movement rates of female European ducks with multistate modelling. *Journal of Animal Ecology*, **72**, 1027-1042.
- Bolker, B. M. (2008) *Ecological Modeling and Data in R*, Princeton University Press.
- Boudjemadi, K., Lecomte, J. & Clobert, J. (1999) Influence of connectivity on demography and dispersal in two contrasting habitats: an experimental approach. *Journal of Animal Ecology*, **68**, 1207-1224.
- Brown, L. (1977) *Birds of prey: their biology and ecology*, Classic Publications, Covina, California.
- Brownie, C., Hines, J. E., Nichols, J. D., Pollock, K. H. & Hestbeck, J. B. (1993) Capture-Recapture Studies for Multiple Strata Including Non-Markovian Transitions. *Biometrics*, **49**, 1173-1187.
- Burnham, K. P. & Anderson, D. R. (2002) *Model selection and multimodel inference : a practical information-theoretic approach*, Springer, New York.
- Cattau, C., Kitchens, W., Bowling, A., Reichert, B. & Martin, J. (2007) Snail Kite Demography Annual Report 2007. pp. 60. US Geological Survey, Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL.
- Clarke, A. L., Saether, B. E. & Roskaft, E. (1997) Sex biases in avian dispersal: A reappraisal. *Oikos*, **79**, 429-438.
- Clobert, J., Danchin, E., Dhondt, A. A. & Nichols, J. D. (2001) *Dispersal*. Oxford University Press, Oxford.
- Cooch, E. G. & White, G. C. (2007) *Program Mark: A Gentle Introduction*.
- Cushman, S. A. (2006) Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biological Conservation*, **128**, 231 - 240.
- Darby, P. C., Bennetts, R. E. & Karunaratne, L. B. (2006) Apple snail densities in habitats used by foraging snail kites. *Florida Field Naturalist*, **34**, 37-47.
- Darby, P. C., Bennetts, R. E. & Percival, H. F. (2008) Dry down impacts on apple snail (*Pomacea paludosa*) demography: Implications for wetland water management. *Wetlands*, **28**, 204-214.
- Darby, P. C., Valentine-Darby, P. L. & Percival, H. F. (2004) Florida apple snail (*Pomacea paludosa* Say) responses to lake habitat restoration activity. *Archiv fur Hydrobiologie*, **161**, 561-575.

- Ellison, L. E., O'Shea, T. J., Neubaum, D. J. & Bowen, R., A. (2007) Factors Influencing Movement Probabilities of Big Brown Bats (*Eptesicus fuscus*) in Buildings. *Ecological Applications*, **17**, 620-627.
- Fahrig, L. (2003) Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology Evolution and Systematics*, **34**, 487-515.
- Ferrer, M. (1993) Juvenile Dispersal Behavior and Natal Philopatry of a Long-Lived Raptor, The Spanish Imperial Eagle *Aquila-Adalberti*. *Ibis*, **135**, 132-138.
- Goffe, W. L., Ferrier, G. D. & Rogers, J. (1994) Global Optimization of Statistical Functions with Simulated Annealing. *Journal of Econometrics*, **60**, 65-99.
- Golden, D. M. & Crist, T. O. (2000) Experimental effects of habitat fragmentation on rove beetles and ants: patch area or edge? *Oikos*, **90**, 525-538.
- Grear, J. S. & Burns, C. E. (2007) Evaluating effects of low quality habitats on regional population growth in *Peromyscus leucopus*: Insights from field-parameterized spatial matrix models. *Landscape Ecology*, **22**, 45-60.
- Greenwood, P. J. & Harvey, P. H. (1982) THE NATAL AND BREEDING DISPERSAL OF BIRDS. *Annual Review of Ecology and Systematics*, **13**, 1-21.
- Griffen, B. D. & Drake, J. M. (2008) Effects of habitat quality and size on extinction in experimental populations. *Proceedings of the Royal Society B-Biological Sciences*, **275**, 2251-2256.
- Haddad, N. M. (1999) Corridor and distance effects on interpatch movements: A landscape experiment with butterflies. *Ecological Applications*, **9**, 612-622.
- Hanski, I. (2001) Population dynamic consequences of dispersal in local populations and in metapopulations. *Dispersal* (eds J. Clobert, A. A. Dhondt, E. Danchin & J. D. Nichols), pp. 283-298. Oxford University Press, Oxford.
- Harmata, A. R., Montopoli, G. J., Oakleaf, B., Harmata, P. J. & Restani, M. (1999) Movements and survival of bald eagles banded in the greater yellowstone ecosystem. *Journal of Wildlife Management*, **63**, 781-793.
- Havens, K. E. & Gawlik, D. E. (2005) Lake Okeechobee conceptual ecological model. *Wetlands*, **25**, 908-925.
- Hestbeck, J. B., Nichols, J. D. & Malecki, R. A. (1991) Estimates of Movement and Site Fidelity Using Mark-Resight Data of Wintering Canada Geese. *Ecology*, **72**, 523 - 533.

- Hinam, H. L. & Clair, C. C. S. (2008) High levels of habitat loss and fragmentation limit reproductive success by reducing home range size and provisioning rates of Northern saw-whet owls. *Biological Conservation*, **141**, 524-535.
- Hovel, K. A. & Lipcius, R. N. (2001) Habitat fragmentation in a seagrass landscape: Patch size and complexity control blue crab survival. *Ecology*, **82**, 1814-1829.
- Ims, R. A. & Hjermann, D. O. (2001) Condition-dependent dispersal. *Dispersal*. (eds J. Clobert, E. Danchin, A. A. Dhondt & J. D. Nichols), pp. 203-216. Oxford University Press, Oxford.
- Johnson, K. G., Allen, M. S. & Havens, K. E. (2007) A review of littoral vegetation, fisheries, and wildlife responses to hydrologic variation at Lake Okeechobee. *Wetlands*, **27**, 110-126.
- Karunaratne, L. B., Darby, P. C. & Bennetts, R. E. (2006) The effects of wetland habitat structure on Florida apple snail density. *Wetlands*, **26**, 1143-1150.
- Kauffman, M. J., Pollock, J. F. & Walton, B. (2004) Spatial structure, dispersal, and management of a recovering raptor population. *American Naturalist*, **164**, 582-597.
- Kitchens, W. M., Bennetts, R. E. & DeAngelis, D. L. (2002) Linkages between the snail kite population and wetland dynamics in a highly fragmented South Florida hydroscape. *The Everglades, Florida Bay, and coral reefs of the Florida Keys: an ecosystem sourcebook*. (eds J. W. Porter & K. G. Porter), pp. 183-203. CRC Press LLC, Boca Raton.
- Lebreton, J. D. & Pradel, R. (2002) Multistate recapture models: modelling incomplete individual histories. *Journal of Applied Statistics*, **29**, 353-369.
- Lenihan, H. S., Peterson, C. H., Byers, J. E., Grabowski, J. H., Thayer, G. W. & Colby, D. R. (2001) Cascading of habitat degradation: Oyster reefs invaded by refugee fishes escaping stress. *Ecological Applications*, **11**, 764-782.
- Macdonald, D. W. & Johnson, D. D. P. (2001) Dispersal in theory and practice: consequences for conservation biology. *Dispersal*. (eds J. Clobert, E. Danchin, A. A. Dhondt & J. D. Nichols), pp. 358-372.
- Martin, J., Kitchens, W. M., Cattau, C., Bowling, A. C., Stocco, S., Powers, E., Zweig, C., Hotaling, A., Welch, Z., Waddle, H. & Paredes, A. (2007a) Snail Kite Demography Annual Progress Report 2006. pp. 128. USGS/Biological Resources Division, Florida Cooperative Fish & Wildlife Research Unit, University of Florida, Gainesville, Florida.
- Martin, J., Kitchens, W. M., Cattau, C. E. & Oli, M. K. (2008) Relative importance of natural disturbances and habitat degradation on snail kite population dynamics. *Endangered Species Research*, **6**, 25-39.

- Martin, J., Kitchens, W. M. & Hines, J. E. (2007b) Importance of well-designed monitoring programs for the conservation of endangered species: Case study of the snail kite. *Conservation Biology*, **21**, 472-481.
- Martin, J., Kitchens, W. M. & Hines, J. E. (2007c) Natal location influences movement and survival of a spatially structured population of snail kites. *Oecologia*, **153**, 291-301.
- Martin, J., Kitchens, W. M. & Speirs, M. (2003) Snail Kite Demography Annual Report 2003. pp. 20. USGS/Biological Resources Division, Florida Cooperative Fish & Wildlife Research Unit, University of Florida, Gainesville, Florida.
- Martin, J., Nichols, J. D., Kitchens, W. M. & Hines, J. E. (2006) Multiscale patterns of movement in fragmented landscapes and consequences on demography of the snail kite in Florida. *Journal of Animal Ecology*, **75**, 527-539.
- McPeck, M. A. & Holt, R. D. (1992) The Evolution of Dispersal in Spatially and Temporally Varying Environments. *American Naturalist*, **140**, 1010-1027.
- McPherson, B. F. & Halley, R. (1996) The south Florida environment : a region under stress. pp. 61. USGS/National Water-Quality Assessment Program.
- Meyer, K. Avian Research and Conservation Institute, Gainesville, Florida.
- Mitsch, W. J. & Gosselink, J. G. (2007) *Wetlands*, John Wiley & Sons, Inc., Hoboken, New Jersey.
- Mossman, C. A. & Waser, P. M. (2001) Effects of habitat fragmentation on population genetic structure in the white-footed mouse (*Peromyscus leucopus*). *Canadian Journal of Zoology-Revue Canadienne De Zoologie*, **79**, 285-295.
- Newton, I. (1979) *Population ecology of raptors*, Buteo Books, Vermillion, South Dakota.
- Nijman, V. & van Balen, S. (2003) Wandering stars: age-related habitat use and dispersal of Javan Hawk-eagles (*Spizaetus bartelsi*). *Journal Fur Ornithologie*, **144**, 451-458.
- Ogden, J. C. (2005) Everglades ridge and slough conceptual ecological model. *Wetlands*, **25**, 810-820.
- Orians, G. H. & Wittenberger, J. F. (1991) Spatial and Temporal Scales in Habitat Selection. *American Naturalist*, **137**, S29-S49.
- Pettorelli, N., Gaillard, J. M., Duncan, P., Maillard, D., Van Laere, G. & Delorme, D. (2003) Age and density modify the effects of habitat quality on survival and movements of roe deer. *Ecology*, **84**, 3307-3316.

- Pickett, S. T. A. & Cadenasso, M. L. (1995) Landscape Ecology - Spatial Heterogeneity in Ecological-Systems. *Science*, **269**, 331-334.
- Real, J. & Manosa, S. (2001) Dispersal of juvenile and immature Bonelli's Eagles in northeastern Spain. *Journal of Raptor Research*, **35**, 9-14.
- Ruiz, G., Rosenmann, M., Novoa, F. F. & Sabat, P. (2002) Hematological parameters and stress index in rufous-collared sparrows dwelling in urban environments. *Condor*, **104**, 162-166.
- Rukke, B. A. (2000) Effects of habitat fragmentation: increased isolation and reduced habitat size reduces the incidence of dead wood fungi beetles in a fragmented forest landscape. *Ecography*, **23**, 492-502.
- Schtickzelle, N. & Baguette, M. (2003) Behavioural responses to habitat patch boundaries restrict dispersal and generate emigration-patch area relationships in fragmented landscapes. *Journal of Animal Ecology*, **72**, 533-545.
- Senar, J. C., Conroy, M. J. & Borras, A. (2002) Asymmetric exchange between populations differing in habitat quality: a metapopulation study on the citril finch. *Journal of Applied Statistics*, **29**, 425-441.
- Sklar, F., McVoy, C., VanZee, R., Gawlik, D. E., Tarboton, K., Rudnick, D., Miao, S., Armentano, T., Porter, J. W. & Porter, K. G. (2002) The effects of altered hydrology on the ecology of the Everglades. *The Everglades, Florida Bay, and coral reefs of the Florida Keys: an ecosystem sourcebook.*, pp. 39-82.
- Smith, J. N. M. & Hellmann, J. J. (2002) Population persistence in fragmented landscapes. *Trends in Ecology & Evolution*, **17**, 397-399.
- Sykes, P. W. (1979) STATUS OF THE EVERGLADE KITE IN FLORIDA - 1968-1978. *Wilson Bulletin*, **91**, 494-&.
- Sykes, P. W., Jr. (1983) Snail kite use of the freshwater marshes of south Florida. *Florida Field Naturalist*, **11**, 73-88.
- Sykes, P. W., Jr., Rodgers, J. A., Jr. & Bennetts, R. E. (1995) Snail kite. *Birds of North America*, **171**, 1-32.
- Sykes, P. W. J. (1987a) The Feeding Habits of the Snail Kite in Florida USA. *Colonial Waterbirds*, **10**, 84-92.
- Sykes, P. W. J. (1987b) Snail Kite Nesting Ecology in Florida USA. *Florida Field Naturalist*, **15**, 57-70.

- Takekawa, J. E. & Beissinger, S. R. (1989) Cyclic Drought, Dispersal, and the Conservation of the Snail Kite in Florida - Lessons in Critical Habitat. *Conservation Biology*, **3**, 302-311.
- Walls, S. S. & Kenward, R. E. (1995) Movements of radio-tagged Common Buzzards *Buteo buteo* in their first year. *Ibis*, **137**, 177-182.
- Walls, S. S. & Kenward, R. E. (1998) Movements of radio-tagged Buzzard *Buteo buteo* in early life. *Ibis*, **140**, 561-568.
- White, G. C. & Burnham, K. P. (1999) Program MARK: survival estimation from populations of marked animals. *Bird Study*, **46**, 120-139.
- White, G. C., Kendall, W. L. & Barker, R. J. (2006) Multistate survival models and their extensions in Program MARK. *Journal of Wildlife Management*, **70**, 1521-1529.
- Williams, B. K., Nichols, J. D. & Conroy, M. J. (2002) *Analysis and Management of Animal Populations: Modeling, Estimation, and Decision Making*, Academic Press, San Diego.
- Zweig, C. (2008) Vegetation Ecology of an Impounded Wetland: Information for Landscape-Level Restoration. *Wildlife, Ecology and Conservation; Florida Cooperative Fish and Wildlife Research Unit*, pp. 128. University of Florida, Gainesville, FL.

BIOGRAPHICAL SKETCH

Andrea Bowling spent her childhood in the concrete jungle of Houston, Texas, where she first began to grow to understand and love wildlife. She graduated from Alief Hastings High School in 1998, moved soon after to Austin and never looked back. She attended and graduated from the University of Texas at Austin in December 2002 with a Bachelor of Science in biology and an option in ecology evolution and conservation. Before and after graduating she took biological technician positions around the states working for not-for-profit organizations, a state agency, and university researchers. The last technician position she took was in the Florida Everglades on a crew collecting data concerning the demography of the snail kite population. This led her to graduate school, where she graduated with a Master of Science in wildlife ecology and conservation in May 2009.