Literature Review of Florida Apple Snails and Snail Kites, and Recommendations for their Adaptive Management

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by The Pomacea Project, Inc.

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On the cover:

Top left: Foraging Snail kite (photo by Tom Lodge); Top right: Snail kite holding a Florida apple snail (photo by Rob Bennetts; Bottom left: Florida apple snail eggs hatching (photo by Michael Robinson); Bottom right: Florida apple snail (photo by Phil Darby).

EXECUTIVE SUMMARY

In the late 1800s and early 1900s, the snail kite subspecies in the U.S. (*Rostrhamus sociabilis plumbeus*), also called the Everglade kite, was described as locally abundant in the areas where it was reported (Sykes et al. 1995). In the U.S., the snail kite only inhabits Florida. Reports of substantially decreasing numbers of snail kites began in the 1930s (Howell 1932, Bent 1937, Sprunt 1945, Sprunt 1954, Wachenfeld 1956, Stieglitz 1965). In the 1940s and 1950s, estimates were that there were only 50-100 snail kites remaining in Florida (Sprunt 1945, Sprunt 1954), and later estimates were that 20 or fewer kites remained (Wachenfeld 1956, Stieglitz 1965). The widespread drainage and conversion of wetlands throughout Florida was named as the primary cause of the kite's population decline. The snail kite subspecies in the U.S. was federally-listed in 1967 as an endangered species. The subspecies is also found in Cuba, and two other subspecies are found in Central and South America (Sykes et al. 1995). The subject of this report is the subspecies found in the U.S., but information on the snail kite in other parts of its range is useful for understanding kite ecology and is presented in some cases.

Although statistically reliable population estimates were not available for the snail kite in Florida until the late 1990's, the number of kites (and kite nests) appeared to be generally holding steady and increasing during the 1980s-1990s (Bennetts et al. 1999a). A number of researchers have studied or monitored the kite since its listing, and valuable information has accumulated on aspects of its life history and ecology, particularly on its nesting ecology, habitat needs, response to environmental conditions, survival, and movements. The population appears to have peaked in 1999 with an estimated 3,400 kites (Cattau et al. 2009; Dreitz et al. 2002a reported 3,577). Researchers report that the population dropped by about 50% from 1999 to 2002. Estimates indicated that the number of kites changed little from 2002 to 2006 (with an estimated 1,400-1,600 kites), but dropped again between 2006 and 2008 (to about 685 kites in 2008; Cattau et al. 2009). Reichert et al. (2011a and 2011b) reported the population to be an estimated 826 birds in 2010 and 925 in 2011. In their assessment of progress of Everglades restoration, the National Research Council (2012) stated that "the conditions are dire" with regards to snail kites. Among 10 critical ecosystem attributes they evaluated, using a grading system from "A" (no significant degradation) to "F" (near irreversible degradation), the condition of the snail kite was assigned the only failing grade (National Research Council 2012). As interest in the snail kite and efforts to restore its population and its ecosystem continues (e.g., with implementation of the Comprehensive Everglades Restoration Plan [CERP]), and

the >10-year population decline persists, it is an appropriate time to revisit our knowledge base for the snail kite and its nearly exclusive prey, the Florida apple snail (*Pomacea paludosa*).

In this document we present the available information on the changes in hydrologic and habitat conditions that may help to explain the declining population, and what hydrologic and habitat conditions should be targeted in support of snail kites. Because habitat conditions in individual wetland units fluctuate frequently (e.g., dry one year, flooded the next), and kites rely on an extensive network of large and small wetland units (some used only occasionally, but at critical times; Bennetts and Kitchens 1997a), management must be adaptive. Agencies that are responsible for long-term management of these wetlands recognize that they require hydrologic variation and periodic disturbances (e.g., dry downs, fire; DeAngelis and White 1994, Kitchens et al. 2002). An adaptive management approach also facilitates the incorporation of emerging information from on-going and future monitoring of snail kites and apple snails and hydrologic and habitat metrics. Chapter 1 of this report provides a further introduction on the plight of the snail kite and our approach to developing this document.

Chapter 2 of the document briefly reviews some of the key investigators and their roles in snail kite and apple snail research and monitoring. We start from the period beginning in the late 1960s, because this is the time that the kite was federally-listed and biologists began annual monitoring of the species in Florida. For the snail kite, research/monitoring during two eras (the annual count era and the telemetry and mark-resighting era) is described, and a discussion on the influence of protocol, scale, and hydrologic perspective is provided. The U.S. Fish and Wildlife Service (USFWS) began conducting an annual survey of the kite in 1969, which continued through 1994. The telemetry and mark-resighting era began in the early 1990s when the groundwork was laid for the mark-resighting program that continues today.

Research and monitoring for the Florida apple snail has been less extensive than that for the snail kite, both in terms of spatial scale and length of time. Prior to 1995, there were fewer than about 15 reports and publications that included direct observations of live apple snails (not just their shells or eggs), and only a handful of these included field observations (e.g., Kushlan 1975, Hanning 1979, Bryan 1990). Because of these early studies and more recent ones, critical information now exists on apple snail reproduction, patterns of egg cluster production, preference for egg-laying substrate, apple snail responses to changing environmental conditions, and tolerance to dry down conditions (i.e., when the water table falls below ground). Early efforts to estimate apple snail densities (i.e., Bennetts et al. 1988) were tested and refined in the 1990s and early 2000s (e.g., Darby et al. 1999, Darby et al. 2005, Valentine-Darby et al. 2008). To date however, only two publications (Darby et al. 2006 and

Darby et al. 2012) and one report (Bennetts et al. 1988) have linked snail abundance to foraging snail kites. Critically important questions remain regarding how snail availability, including density, influences snail kites.

Chapter 2 also provides a description of the current monitoring protocol for the snail kite, including nest monitoring, and methods typically employed to sample apple snails (to estimate density and egg production). Because there is no requirement for annual monitoring of the apple snail, as there is for the snail kite, we provide a table showing the locations (and years) where measurements of snail densities have been made in a series of small-scale studies.

Chapters 3 and 4 of the document provide overviews of the life history, ecology, and range of the snail kite (Chapter 3) and apple snail (Chapter 4). Although many readers are probably familiar with this information, others will find it useful as a background for the subsequent chapters that focus on what appears to influence snail kite and apple snail survival, reproduction, and population growth, emphasizing those factors most affected by management (e.g., water levels, vegetation). The snail kite chapter includes a description of: its physical appearance; diet; nesting, foraging, and roosting habitat; nesting season, clutch size/young produced, and ambisexual mate desertion; nest distribution over time; foraging, prey handling, and snail sizes consumed; causes of kite mortality; parasites and diseases; life span; range; and historic and present decline in distribution and abundance. The apple snail chapter includes a description of: its taxonomy and physical appearance; range, distribution, and general habitat needs; diet; predators; egg-laying; life cycle and breeding season; aestivation and dry season survival; and non-native (or exotic) apple snails and their potential threats.

Chapter 5 focuses on snail kite demography and relationships to hydrology and vegetation. The content is based primarily on research and monitoring of the snail kite in the past ~20 years. Information presented in this chapter includes: estimates of survival and recruitment using annual count data, telemetry data, and mark-resighting data; survival and population trends from 1992-2000 (a relatively wet era) and 2000-present (with periodic low water); age dependent survival; en masse kite movements associated with regional droughts in the 1980s and early 1990s; individually-based quantification of kite movements (including juvenile dispersal from natal wetlands, and monthly and seasonal movements); kite population response to hydrology (1992-present); nest success and low water conditions; high water effects on nesting; management activities to improve snail kite nesting; and the influences of vegetation and water depth on foraging.

Chapter 6 is on Florida apple snail demography and relationships to hydrology and vegetation. Most ecological information on the apple snail is from reports and publications from the late 1960s-1970s and the middle 1990s-present. Information presented in this chapter includes: snail

movements as influenced by water depths; direct and indirect effects of water depth on snail survival, including survival during dry down conditions; effects of water depth on snail recruitment, including receding water and dry down effects, rising water and high water effects, and hydrologic targets for recruitment; the needs of apple snails with regards to vegetation, such as for juvenile snail growth and egg-laying, and snail densities in different vegetation types (in both the Everglades and rivers and lakes in Florida); and studies on water chemistry and contaminant effects on snails, including calcium/pH effects, and effects of nitrate, mercury, organochlorine pesticide residues, and copper.

In Chapter 7, we discuss the influence of apple snail abundance on snail kite foraging, with implications for kite demography. Two studies used indirect measures of snail abundance to examine aspects of kite nesting. In one study, the distance traveled to forage by nesting snail kites was used as a measure of snail abundance (Beissinger and Snyder 1987); it was assumed that the greater the foraging distance, the lower the snail density. In another study, snail kite foraging time was used as a measure of snail abundance (Bennetts et al. 1988), where the greater the foraging time, the lower the snail density. Bennetts et al. (1988) also directly measured apple snail density using 1-m^2 throw traps (the same protocol described in Darby et al. 1999). The chapter also discusses two more recent studies (Darby et al. 2006 and Darby et al. 2012) that examined the relationship between snail density and foraging snail kites. Darby et al. (2006) found a positive association between apple snail densities and the number of foraging kites. Chapter 7 also presents information, based on the handful of studies that have addressed the topic, on caloric gain from snail kite consumption of snails and the associated costs of foraging and other daily activities.

Chapter 8 of the report focuses on snail kite and apple snail population simulation models and tools for estimating habitat suitability for kites and snails. The snail kite population model, *Everkite*, is an individual-based, spatially explicit simulation model that was initially developed to project snail kite population changes under varying hydrologic scenarios (Mooij et al. 2002). Updates and changes have been made to the model (Mooij et al. 2007, Gaines et al. 2008), and the latest version (described in Gaines et al. 2008) includes a grid-based system that reflects water levels at a 2-mile by 2-mile scale (to accommodate data available from the South Florida Water Management Model [SFWMM]), and the addition of more recent biological information (e.g., negative effects of high water on kites due to changes in snail availability and loss of woody nest substrates). Work is currently underway on a spatially explicit apple snail model that will be linked to *Everkite* (Darby et al. 2010). The model is intended to create "what-if" hydrologic scenarios, such as the simulation of drying events of different durations or at different return intervals to predict the response of the snail population. This chapter also discusses the Everglade Kite Nesting Depth Preference Tool developed by Lo Galbo et

al. (2010) to simulate the suitability of water depths within the nesting range of snail kites in Water Conservation Area (WCA) 1, WCA2, WCA3, and Everglades National Park (ENP) during the nesting season. The tool determines the number of days during the nesting season that water depths are within the 20-80-cm range (reported by Bennetts et al. [1988] for 94% of nests). The tool has been used to examine the effects of past changes and expected effects of CERP restoration projects on the snail kite (Lo Galbo et al. 2010). Finally, Darby and Wight (2011) studied seasonal water depths in three wetlands, WCA3A, WCA2B, and Lake Okeechobee (LOKEE), and related the depths to those estimated to be suitable or unsuitable for snail egg cluster production. Their approach was similar to that taken by Lo Galbo et al. (2010); Darby and Wight (2011) determined the number of days that water depths were suitable for egg production during the months of peak egg production (March-June) and other months in which egg production occurs (July-October). [Note that what constitutes depths too high to support snail egg production requires additional study; see recommendations below]. They identified years that were either favorable or unfavorable (too wet or too dry) for snail recruitment based on the seasonality and duration of the water depths.

Chapter 9 of the document presents a synthesis, summary, and conclusions discussion based on the literature review material, Chapters 2-8. This chapter also includes summary tables of trends and associations for snail kites and apple snails, which present key pieces of information about kites or snails that can be used by managers to focus on management goals or targets.

The last two chapters of the main report present recommendations for monitoring, restoration, and management (Chapter 10), and information gaps and recommendations for research pertinent to management (Chapter 11). Recommendations in the report come directly from past or current publications or reports, from Department of Interior (DOI) cooperators, from the report authors, and/or from external peer reviewers of the document (species and habitat experts, the management community). Chapter 10 recommendations are separated into: general recommendations (3 recommendations made); those for management (8 recommendations); those for monitoring (7 recommendations); and those for coordinated information gathering, analysis, and reporting (7 recommendations). Chapter 11 contains research recommendations for snail kites and apple snails (15 recommendations). A shortened version of each recommendation is shown below. This is to give the reader a feel for the recommendations presented in the document, but we refer the reader to Chapters 10 and 11 for a full description of each recommendation. The full descriptions also note the sources of the recommendations.

Our mission in developing this document was to summarize the available data and observations reported on kite and snail responses to changes in wetland habitat conditions in Florida, and from this

information, to the extent possible, develop management targets to support the recovery of the snail kite. Although a multi-species approach has been taken in the South Florida Multi-Species Recovery Plan (USFWS 1999) and CERP, we believe that the downward trend in the kite population over the last decade warrants special emphasis on the snail kite and efforts to reverse the downward trend. The sometimes difficult decision of weighing management options in support of kites and snails as opposed to other management priorities lies with the stakeholders responsible for these species and the wetlands they occupy. Management decisions would, however, be made with the knowledge of conditions that are best, based on the evidence, for kites and/or snails. It is the hope of The Pomacea Project that this report will be a periodically updated, evolving document. As more is learned about the snail kite and the apple snail, existing questions may be partially or fully answered, and new questions may arise. As recommendations for management and research are implemented in an adaptive management framework, some recommendations/actions may need adjustment, and the need for others may become more obvious.

One of the major comments from reviewers of the report was that more specifics on hydrologic conditions that water management should target to support snail kite recovery are needed (see reviewer comments in Appendix B). This lack of specifics reflects the available literature, where the information was either not available, available for only a select few wetlands among the many utilized by kites, or there was a lack of agreement as to what conditions best support kites and snails (see Chapter 9). Providing hydrologic targets for water management that reflect the dynamic conditions of wetland units over the snail kite's entire range is one of the most important information gaps that needs to be filled.

The four appendices to the report present a description of the external review process for the document (Appendix A); the review comments and how they were addressed (Appendix B); a discussion of the metrics used to describe hydrologic conditions, including a case for using water depths in analyses rather than water stage (Appendix C); and information on hydrologic conditions associated with snail kite nesting substrates and foraging habitats (Appendix D).

Chapter 10 Recommendations

A-1. Recommendation: Conserve and effectively manage (and restore, in some cases) the network of habitats, including peripheral habitats (as possible), used by the snail kite in central and southern Florida.

A-2. Recommendation: Management and conservation for snail kites should focus on longer-term trends in snail kite numbers, reproductive success, movements between wetlands, and habitat quality, as well as shorter-term trends in apple snail populations (prey availability).

A-3. Recommendation: As advocated in recent years by multiple researchers, snail kite and apple snail habitat should be allowed to experience occasional dry downs similar to those occurring under natural conditions. Research, *including the analysis of existing data*, needs to be conducted regarding the timing, intensity, duration, and frequency of dry downs to benefit apple snails and snail kites.

B-1. Recommendation: Develop hydrologic targets for management in wetlands deemed critical to snail kites using a similar approach as that used in the USFWS Multi-Species Transition Strategy for WCA3A (USFWS 2010). Targets are needed for seasonal water depths, recession and ascension rates, and dry down return intervals and durations.

B-2. Recommendation: In WCA3A, strive for water levels at the start of the dry season that more closely mimic the natural system, so that water levels would be likely to persist during the kite breeding season under typical drying rates. This recommendation is a more general version of that recommended by Sustainable Ecosystems Institute (SEI; 2007) to address unsuitable conditions that had been occurring during kite nesting in WCA3A.

B-3. Recommendation: Managers of lakes and wetlands used by snail kites should explore and advocate methods or timing of exotic plant control (and other management activities) that are least likely to result in harm to snail kite nests or apple snails.

B-4. Recommendation: For wetland units deemed critical to snail kites, if adult-sized apple snail densities are reported to be less than approximately 0.1-0.2 / m^2, consider management options (see Recommendation B-5) to increase native apple snail densities and otherwise improve snail availability to kites (e.g., via plant management activities). This minimum snail density threshold may need to be revised as additional data are collected.

B-5. Recommendation: In situations where snail availability is deemed too low to support snail kite foraging and/or nesting (see Recommendation B-4), create, to the degree possible, a hydrologic "window of opportunity" that supports apple snail recruitment, growth, and survival. Based on

available information to date, this would mean that between February and June in a particular wetland, an effort should be made to maximize the number of days over the largest area possible, wherein depths stay above 10 cm but do not exceed approximately 40-60 cm. Note that the upper limit of this depth range, in particular, may need revision following additional studies.

B-6. Recommendation: Engage in habitat management practices that promote plant community composition to support apple snail reproduction and relatively high snail densities. Management may include practices such as hydrologic manipulation, prescribed fire, and possibly more intensive plant management practices.

B-7. Recommendation: When managed drawdowns are conducted on lakes in central Florida, they should be timed to avoid the peak period of apple snail reproduction (March or April to June) **and/or** be of a short enough duration (<12 weeks) to allow for the survival of most snails that become stranded in dry marsh.

B-8. Recommendation: Implement public education (and possibly boat checkpoints) and policies, similar to those used to prevent the spread of hydrilla, to reduce the spread and potential impact of exotic ampullariids, especially *Pomacea insularum*, in Florida.

C-1. Recommendation: Provide an annual wetland condition assessment report for wetland units deemed critical or important to snail kites. The assessment should eventually be linked to a habitat suitability index (see Recommendation 11-2 in Chapter 11) and include information on hydrology, prey availability, and plant communities. The wetland condition assessment should include spatially explicit water depths for the current year, the previous year, and previous 5-10 years, the latter to identify long periods of inundation or frequent drying events that may result in habitat degradation and/or low snail densities.

C-2. Recommendation: The annual snail kite range-wide survey should be extended south of Shark River Slough in ENP (recommendation suggested by DOI representatives during development of this document). This would include monitoring in Taylor Slough and the C-111 detention basins. An important component of this long-term kite monitoring is the long-term monitoring of apple snail populations (see Recommendation C-3). This additional monitoring may be especially relevant with the construction and operation of the C-111 detention basins.

C-3. Recommendation: Implement an apple snail monitoring program across the range of the snail kite. Such a range-wide effort should take advantage of monitoring that is ongoing and being conducted at the project-level scale (e.g., in WCA3A as funded by U.S. Army Corps of Engineers [USACE]). Sampling protocols should be standardized, cost-effective, and directly supportive of management. Priority areas to be monitored could be recommended by the Snail Kite Coordinating Team (whose formation is recommended in the report, see recommendation D-1).

C-4. Recommendation: Monitor the spread of exotic apple snails and their influence on native flora and fauna, and if necessary, develop techniques to reduce or eliminate the spread of *Pomacea insularum* (e.g., SEI 2007). Also see research recommendations that directly address questions about this exotic species.

C-5. Recommendation: Implement a monitoring program of snail kite foraging success/efficiency, nest success, and recruitment of offspring as related to apple snail densities and foraging habitat characteristics (i.e., hydrologic conditions, vegetative community compositions; from Cattau et al. 2008 and 2009). An effort to integrate investigations of the effects of hydrology on snail kites, apple snails, and their habitats was also called for in the SEI (2007) report. Also see Recommendation D-4 for such efforts using existing data.

C-6. Recommendation): Given that the estimated snail kite population has decreased considerably in recent years, and snail kites disperse during drought conditions or poor foraging conditions, the use of a clearinghouse for snail kite sightings should be considered. A network of professional biologists and bird watchers throughout the kite's range could be used to report sightings of kites, as well as online approaches, such as eBird.

C-7. Recommendation: Collect data on nest detection probability, and determine whether effort is needed to increase detection in order to find and band more juveniles.

D-1. Recommendation: Establish a Coordinating Team or Committee for the snail kite. The Team's responsibilities should include: 1) forming a consensus on the best hydrologic and habitat conditions to support Florida apple snails and snail kites; 2) assessing the adequacy of apple snail and snail kite monitoring (e.g., is the coverage of apple snail monitoring sufficient?); 3) evaluating the use

of available funds and setting priorities for research and monitoring of kites and snails; 4) annually assessing, or overseeing the assessment of, habitat quality in the wetlands deemed ecologically critical to the snail kite (see Recommendation C-1); 5) developing performance measures for the kite, snail, and their habitats; and 6) developing a communication plan to disseminate key information to natural resource agencies and the public.

D-2. Recommendation: Although some efforts currently exist, increase collaboration and communication between and among researchers and agency personnel. Such efforts could be made at different scales (e.g., an annual or biennial symposium or meeting, a web-based forum for groups studying and managing the species).

D-3. Recommendation: Provide an assessment of the current condition of federally designated critical habitats, and consider updating the critical habitat designation for the snail kite (considering the inclusion of additional areas used by the kite was recommended by USFWS 1999).

D-4. Recommendation: In addition and prior to conducting new/more in-depth investigations of nesting snail kites related to apple snail densities and foraging habitat conditions (see Recommendation C-5), new analyses *of existing data sets* should be conducted to examine possible relationships between apple snail densities (and biomass) and numbers and success of snail kite nests.

D-5. Recommendation: Make every attempt to report apple snail population metrics at a scale relevant to other researchers' work. For example, when sampling apple snail density to assess foraging opportunities for kites, do so at a scale that has relevance to the demography of snail kites.

D-6. Recommendation: In future studies and analyses, characterize hydrologic conditions based on spatially explicit water depths (which account for topography within a wetland unit) whenever possible. Avoid subjective terms like "drought." Reporting seasonal depths has more meaning in ecological terms and can be compared to empirical data that demonstrate kite and snail response to their environment.

D-7. Recommendation: Update this document to incorporate the findings of additional years' snail kite and apple snail monitoring, research, and analyses, and activities of the Snail Kite Coordinating Team (whose formation is recommended in the report).

Chapter 11 Recommendations

11-1. Recommendation: Taking into consideration past reports, analyses should be conducted regarding appropriate return intervals for drying events in apple snail/snail kite habitats. Such analyses could be desk-top and based on existing data.

11-2. Recommendation: Develop a habitat suitability index for snail kites that can be used as a real-time benchmark to assess habitat conditions throughout the snail kite network of habitats.

11-3. Recommendation: Conduct research on the effects of a range of hydrologic metrics (e.g., seasonal depths, recession and ascension rates) that influence and are optimal for apple snail oviposition and recruitment. A combination of laboratory (being cognizant of scale effects), mesocosm, and field studies should be considered.

11-4. Recommendation: Conduct a study to document movement and survival of adult snail kites during widespread drying events (water table below ground level) using satellite telemetry. Although the occurrence of drying events cannot be ensured, a multi-year study would be more likely to capture such conditions. Satellite telemetry data can be used to document movements in response to other changing habitat conditions, including those that influence snail availability, and to identify previously undocumented peripheral habitats.

11-5. Recommendation: Continue development and validation of the snail kite and apple snail demographic models, and provide linkages between the two models.

11-6. Recommendation: Study the conditions that affect mating, reproduction, and dispersal in *Pomacea insularum.* Does *P. insularum* reproduce best under similar conditions as the native Florida apple snail, or, for example, is the species able to exploit a greater range of water depths? The knowledge of such information would assist in controlling this invasive, non-native species.

11-7. Recommendation: Conduct a native apple snail baseline survey in ENP to determine native apple snail distributions and densities within the park. Key questions include determining whether ENP habitats provide viable densities of apple snails for snail kite foraging. The study should be conducted across various vegetation community types and landscape regions (e.g. Taylor Slough vs. Shark River Slough), and over multiple years (with varying climatic conditions).

11-8. Recommendation: Study 1) the occurrence and prevalence of parasites in native Florida apple snails and exotic apple snails (*Pomacea insularum*), and 2) the occurrence/prevalence of parasitic castration in native apple snails in important kite/snail habitats. To the extent that it is feasible, also study the occurrence and prevalence of parasites in snail kites.

11-9. Recommendation: Conduct a study of apple snail distribution and density and egg cluster production within ridge and slough habitats within WCA3A. The study should occur across multiple years and hydrologic and climatic conditions.

11-10. Recommendation: Study whether the invasive exotic *P. insularum* is displacing the native snail in wetlands where it has invaded. A similar recommendation was made by USFWS (2007) and SEI (2007), which suggested research to examine whether the invasive is competing with the native species.

11-11. Recommendation: Conduct studies on abiotic (e.g., temperature, water chemistry [e.g., phosphorus and calcium]) and biotic (e.g., food) factors that influence apple snail growth using a combination of field studies, lab studies (to better control conditions and monitor individual growth rates), and possibly *in situ* mesocosm studies.

11-12. Recommendation: Study the effects of fire on apple snail availability to snail kites. Fire is a management tool that may influence nutrient availability and, consequently, snail growth, as well as habitat structure, which affects both snails and kites.

11-13. Recommendation: Conduct a field study of the effects of water chemistry on the distribution and abundance of apple snails, and parameterize the developing apple snail demographic model to include water chemistry.

11-14. Recommendation: Conduct additional studies on the effects of predation on apple snail populations (i.e., densities). These studies should include avian and aquatic predation over a range of hydrologic conditions, because apple snails are subject to predation both when wetlands are flooded and under dry down conditions.

11-15. Recommendation: Sample soils, water, vegetation / periphyton, apple snails, and as available, snail kites, for copper in order to determine whether there is a negative impact of copper on apple snails or snail kites.

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ACRONYMS AND ABBREVIATIONS

AIC	Akaike's Information Criterion
ARCI	Avian Research & Conservation Institute
BCNP	Big Cypress National Preserve
BCMCA/BCWMA	Blue Cypress Marsh Conservation Area/Blue Cypress Water Management Area
CERP	Comprehensive Everglades Restoration Plan
CI	Confidence Interval
CJS	Cormack-Jolly-Seber
CV	Coefficient of Variation
DBHYDRO	Environmental Database of the South Florida Water Management District
DOI	Department of Interior
DSV	Drought Score Value
EDEN	Everglades Depth Estimation Network
East LTOHO	East Lake Tohopekaliga
ENP	Everglades National Park
FC	First Count
FFWCC	Florida Fish and Wildlife Conservation Commission
GWP	Grassy Waters Preserve
HWE	High Water Event
KCOL	Kissimmee Chain-of-Lakes
LISTOK	Lake Istokpoga
LNWR	Loxahatchee National Wildlife Refuge
LKISS	Lake Kissimmee

LOKEE	Lake Okeechobee
LTOHO	Lake Tohopekaliga
MC	Maximum Count
PCE	Per Capita Egg Production
SAV	Submerged Aquatic Vegetation
SD	Standard Deviation
SE	Standard Error
SEI	Sustainable Ecosystems Institute
SFWMD	South Florida Water Management District
SFWMM	South Florida Water Management Model
SJM	St. Johns Marsh
STA	Stormwater Treatment Area
UF	University of Florida
USACE	United States Army Corps of Engineers
USDOI	United States Department of the Interior
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USJM	Upper St. Johns Marsh (same as SJM)
UWF	University of West Florida
WCA	Water Conservation Area
WCA1	Water Conservation Area 1
WCA2A	Water Conservation Area 2A
WCA2B	Water Conservation Area 2B
WCA3A	Water Conservation Area 3A

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CHAPTER 1: NEED FOR THE DOCUMENT AND APPROACH TO ITS DEVELOPMENT

NEED FOR THE DOCUMENT

Since its listing as federally endangered in 1967, the North American subspecies of snail kite (*Rostrhamus sociabilis plumbeus*), also called the Everglade snail kite (see Chapter 3), has been monitored yearly and studied by dozens of university researchers and agency biologists. The result has been more than 75 peer-reviewed publications, about 40 technical reports (a conservative estimate), and several book chapters that describe snail kite life history, habitat needs, and responses to hydrology. Additional research on snail kites outside of Florida also shed light on foraging behavior, energetic needs, and habitat use. Although studied less extensively, and with many fewer peer-reviewed publications to address it, the native Florida apple snail (*Pomacea paludosa*), the kite's nearly exclusive food, has also been described and studied in the context of its hydrologic and habitat needs. There have been paradigm shifts in how we see snail kite use of a network of wetland habitats (see Bennetts et al. 1998a) and how apple snails adapt to drying events, events once thought to be catastrophic to the kite's food supply (see Darby et al. 2008). More than fifteen years of continuous mark-resighting data (1994-2011) and three years of radio telemetry data (1992-1995) have been analyzed and reanalyzed using different models (see publications listed in Literature Cited by Bennetts et al., Dreitz et al., Martin et al., and Reichert et al.) to characterize patterns of snail kite survival and movements. Several demographic models were developed to understand the relative contribution of kite mortality and kite recruitment to changes in kite abundance (Nichols et al. 1980, Beissinger 1995, Moojii et al. 2002 and 2007, and Martin et al. 2007a). Two major workshops (in 2003 and 2007), both lead by the Sustainable Ecosystems Institute (or SEI), and many smaller ones (Phil Darby, University of West Florida [UWF], pers. obs.), updated stakeholders on new data and data gaps to facilitate snail kite recovery.

Despite this apparent wealth of information and efforts to disseminate it, stakeholders continue to express a need for more and better information on how to manage water and create habitat conditions to support snail kites. As the amount of information on both kites and snails has dramatically increased (especially from 1995-today, in terms of peer-reviewed publications), the snail kite population has declined by an estimated 50% or more since 1999 (see below). Our overall objective in preparing this document was to synthesize existing information on snail kite and apple snail ecology, while trying to understand the apparent disconnect between an increase in the amount of data on kites and snails and the concurrent decrease in kite abundance. Has the historic information been inadequate as far as understanding the needs of kites and snails? Has the

information been presented in a way that does not address management needs? Have managers (or policy makers) not taken appropriate action based on the available information? Has the scope of the problem and its potential impacts on other components of the system prohibited appropriate action? Has the network of habitats historically utilized by snail kites been degraded to an extent that the accumulated data no longer apply, and we need more information to understand the "new reality" for what kites face in south and central Florida wetlands? These are the types of questions that have emerged from meetings and workshops, and that we hope to address through development of this document.

In the late 1800s and early 1900s, the snail kite was described as locally abundant in the areas where it was reported (Sykes et al. 1995). Reports of substantially decreasing numbers of kites began in the 1930s (Howell 1932, Bent 1937, Sprunt 1945 and 1954, Wachenfeld 1956, Stieglitz 1965). Sprunt (1945) estimated that there were only 50-100 snail kites remaining in Florida in the 1940s and 50-75 kites in the 1950s (Sprunt 1954). Subsequent estimates were that 20 or fewer snail kites remained (Wachenfeld 1956, Stieglitz 1965). Whether or not these estimates underestimated the remaining kite population, they indicated that the snail kite population was in decline and low in number (Sykes et al. 1995). The snail kite was listed as endangered in 1967, and an annual count of the species was conducted from 1969-1994. These counts, described in detail in Chapters 3 and 5, reported kite numbers from 65 (in 1972) to 996 (in 1994; summarized in Bennetts et al. 1999a). Sampling limitations of the annual count led Bennetts and Kitchens (1997a) to begin a systematic banding protocol that would become the foundation for a mark-resighting survey of snail kites. The mark-resighting survey enables survival and population estimates to be made. Using these methods, the population size has been estimated annually since 1997 (Dreitz 2000; see details in Chapters 2 and 3).

From 1997-2010, the snail kite population was estimated to be at its highest in 1999, at an estimated 3,400 kites (Cattau et al. 2009; Dreitz et al. 2002a reported 3,577 kites). This was around the time that the South Florida Multi-Species Recovery Plan was produced (U.S. Fish and Wildlife Service [USFWS] 1999). The population dropped by about 50% from 1999 to 2002 (Cattau et al. 2009). Estimates indicate that the population fluctuated little from 2002 to 2006 (with an estimated 1,400-1,600 kites; Cattau et al. 2009), but dropped again between 2006 and 2008 (to about 685 kites in 2008). Reichert et al. (2011a, 2011b) reported the population to be about 826 birds in 2010 and 925 in 2011. In their assessment of progress of Everglades restoration, the National Research Council (2012) stated that "the conditions are dire" with regards to snail kites. Among 10 critical ecosystem attributes they evaluated, using a grading system from "A" (no significant degradation) to "F" (near irreversible degradation), the condition of the snail kite was assigned the only failing grade (National

Research Council 2012). This decline from the estimated population in 1999 has been at the root of the increase in information requests from the management community.

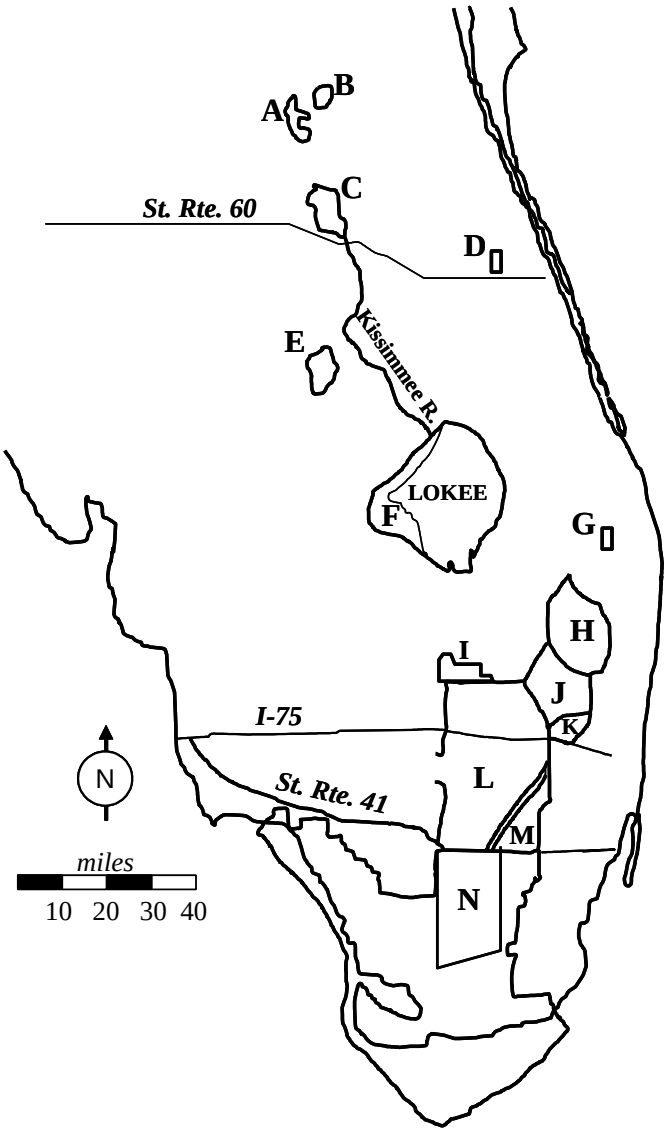
Today, the snail kite population resides primarily in the Kissimmee-Okeechobee-Everglades drainage basin (Sykes et al. 1995), the watershed that originates in the Kissimmee Chain-of-Lakes and flows southward to Everglades National Park (ENP; Light and Dineen 1994; see Figure 1-1). Historically, the range of the snail kite in Florida was larger, and widespread wetland drainage throughout the state is considered the primary cause of the kite's population decline (e.g., Howell 1932, Sprunt 1945, Bennetts et al. 1994). For example, about 50% of the wetland habitat available to kites in the southern half of the Florida peninsula has been lost since the early 1900s (Sykes 1983b). This habitat loss was due largely to the drainage of vast portions of the Everglades, and hydrologic modification and manipulation of other portions of the system, including the impoundment and compartmentalization of some areas (Stieglitz and Thompson 1967, Bennetts et al. 1994, Sykes et al. 1995, USFWS 1999, Sklar et al. 2002, McVoy et al. 2011). In recent years, the geographic boundaries of the major wetlands known to be used by snail kites have remained intact, and billions of dollars have been/are being spent to restore historic flows and improve habitat structure in support of wetland-dependent wildlife. Clearly, wetland loss alone cannot explain the recent decline in snail kites. More subtle changes in seasonal water depths and shifts in habitat structure, including those that impact apple snail abundance (Darby et al. 2004, Darby et al. 2005), as well as climatic events (i.e., drought; Cattau et al. 2009), have probably contributed to the snail kite decline.

In this document we present the best available evidence of what changes in hydrologic and habitat conditions explain these trends, and what hydrologic and habitat conditions should be targeted in support of snail kites. Because habitat conditions in individual wetland units fluctuate frequently (i.e., dry this year, flooded the next), and kites rely on an extensive network of wetland units (some used only occasionally, but at critical times), management must be adaptive. Long-term management of these wetlands requires hydrologic flux and periodic disturbances (e.g., dry downs, fire; DeAngelis and White 1994, Kitchens et al. 2002). In this document, we will not make recommendations for stabilization or indefinite maintenance of "optimal" hydrologic and habitat conditions; attempts to do so have been shown to eventually result in ecosystem degradation (see Holling and Meffe 1996). An adaptive management approach also facilitates the incorporation of emerging information derived from on-going monitoring of snail kites, apple snails, and hydrologic and habitat conditions.

APPROACH TO DEVELOPING THE DOCUMENT

The emphasis of this report is on the natural and managed factors that affect snail kites and apple snails and how this information can be used for adaptive management. For example, this report

Figure 1-1. Major wetland units used by snail kites. Year to year use of different wetland units can vary considerably. This map shows the general distribution since ~1995. Wetland units shown are: A) Lake Tohopekaliga, B) East Lake Tohopekaliga, C) Lake Kissimmee, D) Upper St. Johns Marsh, E) Lake Istokpoga, F) western marshes of Lake Okeechobee (LOKEE), G) Grassy Waters Preserve, H) Water Conservation Area (WCA) 1, I) Rotenberger and Holey Land Water Management Areas, J) WCA2A, K) WCA2B, L) WCA3A south of I-75, M) WCA3B, and N) portions of Everglades National Park. Scale is approximate.



addresses direct relationships between seasonal water depths (as influenced by water management) and kite and snail reproduction. Emphasis is placed on available data sets and peer-reviewed literature directly related to snail kite and apple snail life history and habitat needs. However, many qualitative observations and data pertinent to snail kite conservation can be found in technical reports and other sources, and these sources are used as well. The information reviewed for the plan focuses on snail kites, apple snails (native primarily), wetland habitats, wetland vegetation, and hydrology. A comprehensive literature list was developed by compiling 1) published literature from about the last 30 years (and in some cases earlier) that focuses on snail kites and apple snails, and 2) research/ monitoring reports prepared for government agencies (e.g., USFWS, U.S. Army Corps of Engineers [USACE]) on kites and snails. In the last ~18 years, annual monitoring of snail kite demography was conducted by the Florida Cooperative Fish and Wildlife Research Unit at the University of Florida (UF; Wiley Kitchens, Principal Investigator), and various population monitoring and research projects on apple snails were conducted by Phil Darby and staff at UWF. The majority of the data collected in the last 2-5 years have not been published, so we relied primarily on available technical reports, understanding they may not have been peer-reviewed. An initial list of potential references was reviewed by the Department of Interior (DOI) at the onset of this project, and additional publications/reports were added to the list as they became available or were discovered.

This report benefited from an external review process that included three recognized experts in 1) avian ecology, 2) invertebrate ecology, and 3) wetlands ecology (including hydrology and wetland plant community development). Several additional reviewers from the management community (e.g., with South Florida Water Management District [SFWMD], Florida Fish and Wildlife Conservation Commission [FFWCC]) that deal directly with issues related to snail kites, apple snails, and/or wetlands management also provided valuable input on the draft document. For a more detailed description of the external review process, see Appendix A. The Pomacea Project, Inc. proposed the inclusion of the external review process so that the report would benefit from each reviewer's expertise, and to help build a consensus for recommendations in the report. The reviewers provided written comments. Appendix B shows the comments in a comment matrix, as well any cover letters provided by reviewers. The Pomacea Project provided a written response to every comment in the matrices, although in some cases this did not result in a change in the document itself. We intend for this document to be updated on a periodic basis in order to address new data that shed light on how to improve conditions for apple snails and snail kites.

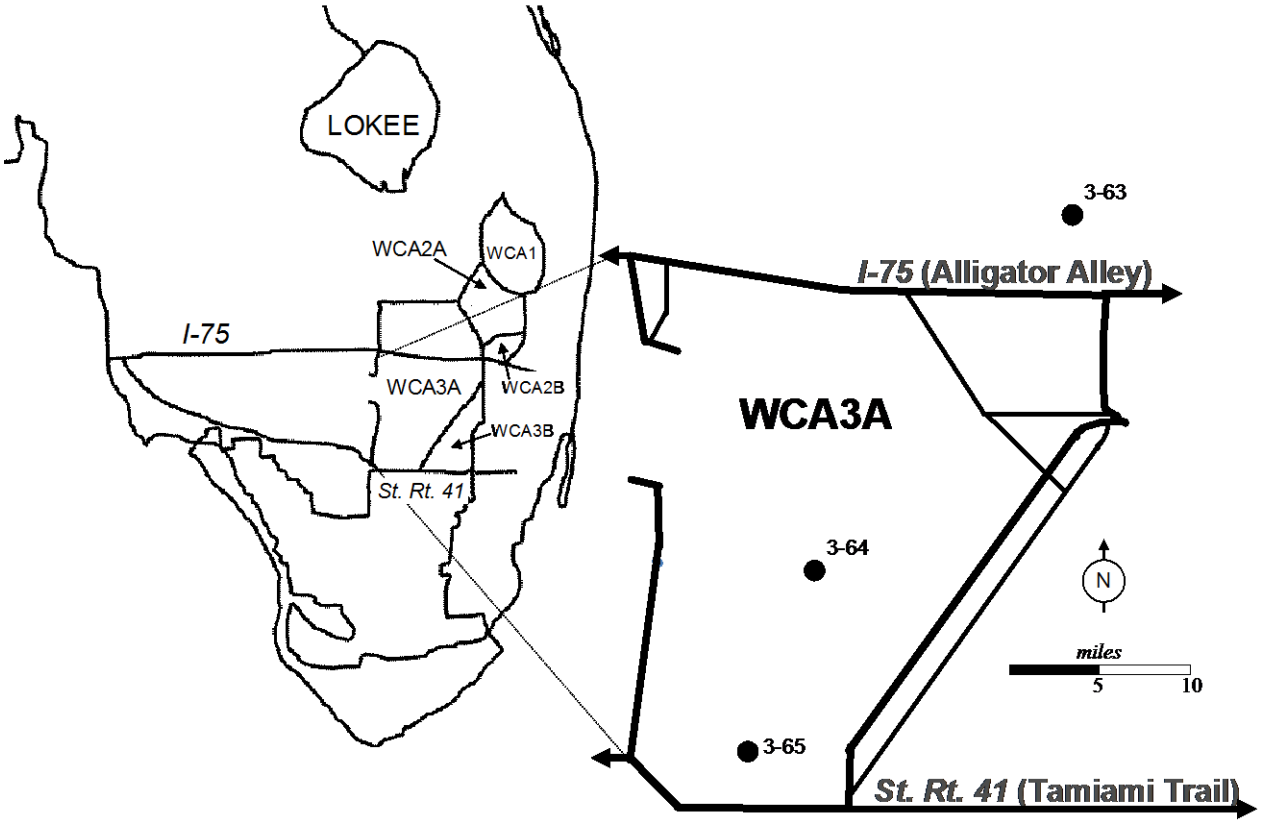
CHAPTER 2: THE HISTORY OF SNAIL KITE AND APPLE SNAIL MONITORING AND RESEARCH

As we reviewed the entire body of pertinent literature, we realized that fully understanding how to interpret ecological trends and patterns reported for snail kites and apple snails required understanding the prevailing conditions and methods deployed throughout the differing hydrologic and kite demographic eras that have existed. Although many of the estimates made by early investigators (e.g., kite life span exceeds 18 years, Nichols et al. [1980]) have been validated by additional data and analyses (age-dependent survival analyses, Reichert et al. 2010), there are some discrepancies, some of which may be based merely on a lack of data early on. This was primarily an issue for snail kite research and monitoring; apple snails had not been studied extensively, nor were there routine field monitoring data in the early days of kite monitoring. Here we describe the history of snail kite monitoring and research, followed by that for apple snails. We emphasize the period beginning with when routine snail kite surveys were initiated (1969).

To support our discussion of what were considered by researchers as dry or drought years compared to relatively wet years (periods with greater depths for longer periods), we provide stage data from Water Conservation Area (WCA) 3A so the reader can see the quantitative difference in these qualitative terms; *see* the footnotes and Figures 2-1 and 2-2 in this chapter). We use WCA3A as a reference, because: 1) it supported the majority of snail kite recruitment in many years (Martin et al. 2007b); 2) total recruitment in the kite population closely tracked recruitment in WCA3A (until the last several years; Martin et al. 2007b); 3) WCA3A is still considered critical to snail kite population recovery (Kitchens et al. 2007); 4) it is the largest of 10 wetlands included in the kite survey from 1969 through today (Bennetts et al. 1999a); and 5) we have continuous stage data and/or depth estimates going back to 1967 (e.g., see Bennetts et al. 1998a, Zweig and Kitchens 2008, Darby and Wight 2011). References to WCA3A conditions apply only to the wetland area south of I-75 (see Figure 2-1). In using WCA3A as a primary example of dynamic hydrologic conditions and kite use, we do not necessarily mean that WCA3A is more critical to the future recovery of snail kites than any other wetland unit in the kite's historic range.

The following discussion by no means represents all of the important contributions made by numerous individuals to our understanding of these species and their habitats (see more details in Chapters 3 to 6).

Figure 2-1. Map showing Everglades wetland unit WCA3A, with portion bounded by I-75 to the north and St. Route 41 to the south. Other wetland units shown for geographic reference. LOKEE = Lake Okeechobee, WCA = Water Conservation Area. Symbol (●) shows approximate location of water stage gauges at Station 3-63 (north of I-75; at Site 3A-3), Station 3-64 (Site 3A-4), and Station 3-65 (Site 3A-28). Gauge station and site designations from DBHYDRO (SFWMD hydrology data). Scale is approximate.



SNAIL KITE RESEARCH AND MONITORING

The Annual Count Era

Estimates of fewer than 100 snail kites, and even as few as 20 or less (Wachenfeld 1956, Stieglitz 1965, as cited in Sykes et al. 1995, see Chapter 3), prompted the USFWS to list *R. s. plumbeus* as endangered in 1967. USFWS biologist Paul Sykes made a preliminary assessment of the wetlands that kites occupied from 1967-1968. The annual survey (characterized as a census, i.e., a complete count; a characterization that would later be disputed) of the kite population began in 1969 (Sykes 1979, 1984). As reported in Rodgers et al. (1988), "Sykes (pers. comm.) usually conducted the …survey by himself…." From this time until 1980, Sykes studied the status, distribution, life history, and ecology of the species in Florida (Sykes 1984; see Chapters 3 and 5). He also conducted nest surveys, monitored nest success, and banded nestlings (Sykes 1979). The relatively low numbers of snail kites reported from annual counts from 1969-1978 (~50-220) were significantly influenced by the relatively low number of observer-days (~10-15) associated with these surveys (Bennetts et al. 1999a). Consequently, as survey effort increased from 1975-1980, from 8 up to 35 observer days, the number of kites counted increased over these years (Bennetts et al. 1999a); 650 birds were counted in 1980. In addition, annual kite counts were often influenced by dry downs in critical wetlands from 1969-1980[1,2]. In this report, we define a dry down as when the water table falls below ground level; also see Appendix C. Bennetts et al. (1999a) concluded that population growth rates ($\lambda > 1.0$) were likely an artifact of increased survey efforts.

In 1981, biologist James Rodgers, Jr., (Florida Game and Freshwater Fish Commission, now the Florida Fish and Wildlife Conservation Commission, FFWCC) took over the annual snail kite count. FFWCC also solicited count data from biologists working in particular areas (e.g., ENP; see Rodgers et al. 1988). Nineteen eighty-one happened to be a peninsular-wide drought year[3]. Rodgers (1983) reported that Lake Okeechobee (LOKEE), WCA2B, and WCA3A were "nearly dried up" (precisely when was not indicated). He reported approximately 21 observer days for the fall survey (down from 35 days in 1980). The kite count from the survey dropped to 109 snail kites. Rodgers

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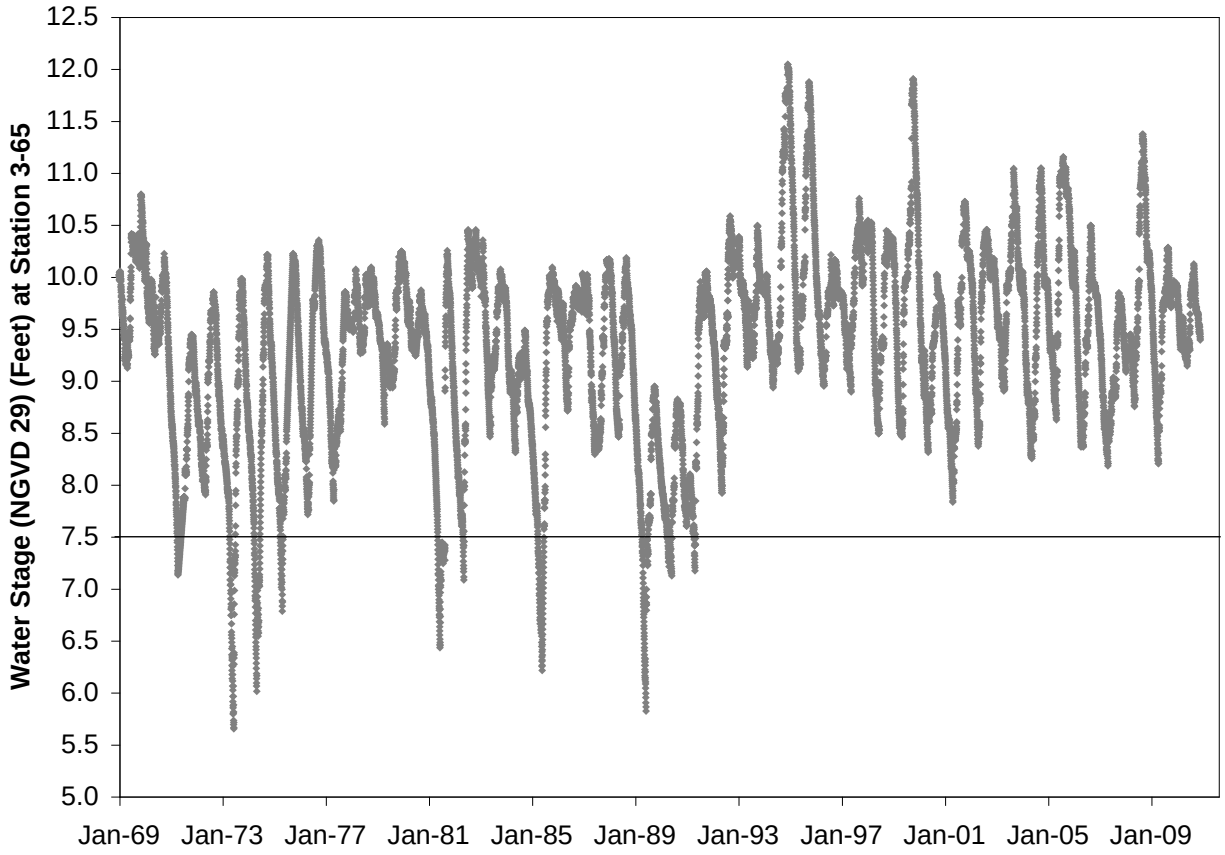
[1] As described on the first page of this chapter, we reference specific water levels for WCA3A to help put in perspective the relative wet and dry conditions during differing eras of snail kite monitoring. In addition to the reasons for using WCA3A, the area has also received the most attention in terms of studies of kite nesting ecology, prey density, and analyses of hydrologic conditions that support snails and kites. Also see the first paragraph in the next section (Telemetry and Mark-resighting Era).

[2] From 1969-1980, water stages in WCA3A averaged ~8.2 ft (2.5 m) above Mean Sea Level (MSL) (gauge at Station 3-65 [Station 3-65 = Site 3A-28]), fluctuating mostly between 7.9-9.8 ft (2.4-3.0 m) above MSL (except where stage fell below 7.5 ft [2.3 m], leaving much of WCA3A dry [i.e., 1973, 1974, 1975]; Figure 2-2).

[3] WCA3A stage fell to 6.46 ft (1.97 m) MSL (June 1981) and stayed low throughout the summer (Figure 2-2).

Figure 2-2. WC3A water stage (gauge at Station 3-65 [Site 3A-28]) from 1969-2010 in feet above mean sea level (MSL) based on National Geodetic Vertical Datum 29 (NGVD 29), as reported by DBHYDRO. Ground level at 7.5 feet (2.29 m) shown for reference (7.5 feet reflects the approximate elevation at the southern-most [and deepest] area of WCA3A). For location of gauge at Station 3-65, see Figure 2-1. Note that this figure is cited in the footnotes and text in this chapter.



(1983) referred to a "black hole" where uncounted kites had likely dispersed, and reported anecdotal evidence of kites observed outside the survey area (e.g., canals, the Suwannee River [i.e., "drought-related" sites per Beissinger and Takekawa 1983, or "peripheral sites" per Valentine-Darby et al. 1998]). From 1982 to 1990, the annual count was conducted for 20-30 days; counts peaked at about 650 snail kites in 1984, a relatively wet year[4]. In 1985, drought conditions returned[5], kites dispersed again, and the fall count was down to 400 birds. As stated by Rodgers (1983), "under these environmental conditions [meaning drought], surveys lose much of their accuracy."

Steven Beissinger (formerly at Yale University, now at University of California at Berkley) and Noel Snyder (USFWS) were never responsible for the annual kite count, but they provided important descriptions of behavior and conducted research on snail kite foraging and nesting (see Chapter 3). Both Beissinger and Snyder also conducted research on kites in other countries. Snyder also reported on some aspects of apple snail behavior (Snyder and Snyder 1971). Most of Beissinger and Snyder's work on snail kites in Florida was conducted in the 1980s. Beissinger's work included observations of kite response to the droughts of 1981 and 1985, and kite dispersal to formerly undocumented lakes and drought-related sites not included in the annual count (Takekawa and Beissinger 1989). Beissinger (1995) used annual kite count data from 1969-1988 (primarily from Sykes and Rodgers, see above) to model the effects of environmental conditions (e.g., drought) on kite demography, and to predict extinction under a range of hydrologic scenarios.

Telemetry and Mark-resighting Era

Robert Bennetts (initially working with Mike Collopy, UF, and in collaboration with Beissinger) started working on snail kites in 1986, focusing, at that time, entirely on kite nesting ecology in WCA3A. The nest study period (1986-1987) coincided with relatively high water years, but also followed the 1985 drought (most of WCA3A was dry from April-July 1985)[5]. Bennetts et al. (1988) also reported the first documented apple snail densities (just two sites), and these data, combined with foraging data and the number of kite nests (148 and 227 in 1986 and 1987, respectively), suggested apple snails were relatively abundant (see more details in Chapter 7). Bennetts (with W. Kitchens, Florida Cooperative Fish & Wildlife Research Unit, UF) took responsibility for the kite survey from 1991-1994. Bennetts et al. also initiated a systematic banding protocol as the foundation for a mark-resighting survey of snail kites (which would eventually replace

[4] WCA3A stage was between 8.30 to 9.88 ft (2.53 to 3.01 m) MSL all year; Figure 2-2.

[5] WCA3A stage dropped to 6.20 ft (1.89 m) MSL, and most of WCA3A was dry from April-July; Figure 2-2.

the annual fall count), from which population and survival estimates were, and continue to be, made (Bennetts and Kitchens 1997a). At the same time, they outfitted 271 snail kites with radio transmitters to document movements and survival. Telemetry data from 1992-1995 coincided with a relatively wet period (e.g., portions of the Everglades that had dried-down in the 1970s-1980s remained flooded year-round from 1992-1995)[6]. To reiterate, all of the 1992-1995 data reported from telemetry and mark-resighting studies were associated with relatively wet conditions (and in some years record highs), with no influence from dry down conditions.

By 1995, the annual snail kite count was discontinued, and all population and survival estimates since then have been based on breeding season (March-June) mark-resighting surveys. Florida Cooperative Fish & Wildlife Research Unit students and staff have been responsible for the breeding season survey from 1996 through present (W. Kitchens, Principal Investigator). Details on the mark-resighting study and annual nest monitoring are provided below, as well as in Chapter 5. Relatively wet conditions continued in the Everglades through 1999[7]. The relatively wet period immediately preceded a decline in kite nesting in WCA3A, from 168 and 178 known active nests in 1997 and 1998, respectively, down to 66 known active nests in 1999 (Dreitz and Kitchens 1997, Dreitz et al. 2000). WCA3A has long been considered a critical area to the snail kite population in terms of nesting and recruitment. The prolonged high water period also preceded a decline from a peak snail kite population in 1999 (3,400 kites per Cattau et al. 2009, or ~3,500 kites per Dreitz et al. 2002a) down to fewer than 3,000 birds in 2000, and continued declines thereafter (Martin et al. 2007b). [The most recent population estimate was 925 snail kites in 2011 (Reichert et al. 2011b)]. Since 2000 in WCA3A, there has been an alternating series of relatively dry years (2001, 2004, 2006, 2007, and 2009; but never as dry as several dry years from 1970-1991), and relatively wet years (2003, 2005, and 2010, with most of WCA3A south of I-75 remaining flooded all year; see Figure 2-2 for hydrologic trends). Kites have largely abandoned WCA3A for nesting since 2003 (Martin et al. 2007b). Darby et al. (2005) documented a significant decline in snail density, especially in southern WCA3A, that corresponded temporally to fewer kites nesting there. During the same period, the exotic apple snail, *Pomacea insularum*, became dominant on Lake Tohopekaliga (LTOHO), and snail kite nesting activity increased on the lake (Cattau et al. 2009).

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[6] In 1992, northern portions of WCA3A were dry in May-June, but southern WCA3A remained flooded year-round; in 1993-1995, all of the WCA remained flooded year-round. Record high water stages occurred in the WCA (1994-1995, in which stages exceeded 12.6 ft [3.85 m] MSL, or 19.7 in [50 cm] higher than the highest water stages recorded as far back as 1970; Figure 2-2).

[7] Nearly all of WCA3A remained inundated, albeit with declining water levels compared to 1995 (water stage rarely exceeded 10.5 ft (3.2 m) MSL from 1996-1999, Figure 2-2).

THE INFLUENCE OF PROTOCOL, SCALE, AND HYDROLOGIC PERSPECTIVE

Interpreting the long-term trends in snail kite demography has been complicated by variation in level of effort, different eras of hydrologic conditions, different sampling protocols, consideration of different spatial and temporal scales, and different approaches to analyses. Although we do not expect all stakeholders in snail kite conservation to critically analyze all manuscripts and reports (one of the reasons behind development of this document), stakeholders should be aware that the way data were collected and analyzed does affect what we conclude about kite response to environmental conditions. One such example is a critique published by Beissinger and Snyder (2002) of a paper by Dreitz et al. (2001), which was then followed by a rebuttal by Dreitz et al. (2002b). Depending on what scale was considered for the analyses (range-wide, per Dreitz et al. or individual wetlands, per Beissinger and Snyder), and what models were selected for analyses, there was not (Dreitz et al.) or there was (Beissinger and Synder) a significant effect of water level on nest success. Another discrepancy involved stage data, and criteria by which investigators define a "drought" (i.e., low enough water levels to impact kites) (see "drought semantics," p. 106, Bennetts and Kitchens 1997a). Both Bennetts et al. (2002) and Martin et al. (2006a) defined wet and dry years based on deviation from a long-term period average. Bennetts et al. (2002) calculated a 30-yr (± SD) average water stage for WCA3A (1965-1994); Martin et al. (2006a) calculated an 11-yr (± SD) average (1992-2003). A drought year was identified as a year in which stage was 1 SD below the long-term average. The difference was that the 30-yr average for 1965-1994 was ~30 cm lower than the 11-yr average for 1992-2003. As a result, Martin et al. (2006a) characterized 1992 as a drought year; Bennetts et al. (2002) found 1992 to be an average year (0.14 SD above the long-term average [actual SD taken from Bennetts and Kitchens 1997a, p. 109]). These details become important as we attempt to identify the magnitude of kite and snail response to hydrologic conditions and their associated ecological significance. Equally important is how management agencies interpret the impacts of "drought" as discussed in research publications and reports (see Appendix C on drought semantics).

RESEARCH AND MONITORING OF SNAIL KITES: CURRENT PROTOCOLS

Population Monitoring – Every year multiple surveys of the same wetlands are conducted at 2-3 week intervals from 1 March to 30 June (Cattau et al. 2009). Binoculars and spotting scopes are used to obtain a view of every snail kite sighted. Every sighted kite is categorized into one of three groups: 1) marked (the kite is banded and can be uniquely identified); 2) unmarked (the kite does not have an identifiable band) and; 3) unknown (banding status cannot be determined). The wetland areas surveyed each year are the Kissimmee Chain-of-Lakes (e.g., Lakes Tohopekaliga [LTOHO], Kissimmee [LKISS], and East LTOHO), St. John's Marsh (SJM, including East and West portions of

the Blue Cypress Marsh Complex), Lake Istokpoga (LISTOK), LOKEE, Loxahatchee Slough and surrounding wetlands (e.g., Loxahatchee National Wildlife Refuge [LNWR], Grassy Waters Preserve [GWP], Corbett Wildlife Management Area), WCAs 3A, 3B, 2A, and 2B, ENP, Big Cypress National Preserve (BCNP), and the Stormwater Treatment Areas (STAs) (Reichert et al. 2011b).

Nest Monitoring - Nest monitoring is also conducted on an annual basis, but it is not limited to any specific survey period (Cattau et al. 2009). "Pre-season" nest searches are conducted November-February in wetlands known to support kite breeding. During other times, nest monitoring is done whenever reproductive behavior is observed. This occurs especially between March and June during population surveys, as well as during other year-round activities such as banding or radio-tagging individuals. Nests are checked using telescoping mirror poles, and data are collected on the number of eggs, status of the nest, nest substrate, nest height, water depth (at some nests), and nest location. Data on the fates of nests are collected, and failed nests are categorized into one of four groups: 1) predation or post scavenging event with no nest collapse; 2) predation or post scavenging event with nest collapse (where collapse was probably caused by a land predator, such as a raccoon); 3) nest collapse; or 4) unknown nest failure, including nests that could not be relocated (Reichert et al. 2011a). A successful nest is one in which at least one chick fledged (Cattau et al. 2009). Snail kite nestlings are banded at approximately 24 days of age with unique alpha-numeric bands. Olbert (2011) described the use of game cameras to monitor nests and study the causes of nest failure; see Chapter 5 for some preliminary findings of this work. The annual kite monitoring reports (e.g., Cattau et al. 2009) provide a tabular summary, for each wetland surveyed, of the number of active nests (those having at least one egg), the number of failed and successful nests, and the number of young produced.

RESEARCH AND MONITORING OF APPLE SNAILS

Historic Overview

Interpreting snail kite demographic trends and wetland occupancy patterns has also been complicated by a lack of information (and some misinformation) on the status of apple snails in critical kite use areas. We found fewer than 15 reports and publications that included direct observations of live Florida apple snails (not just their shells or eggs) prior to 1995, and only six of these included field observations (i.e., Perry 1973, Hurdle 1974, Kushlan 1975, Hanning 1979, Bennetts et al. 1988, Bryan 1990). In over 30 years of monitoring kites, there were virtually no data on snail densities and/or availability that could help explain snail kite population trends or wetland occupancy patterns. Given their dietary specialty, some measure of the food supply is essential to understanding the relative magnitude of the influence of prey abundance, hydrology, water quality,

and plant community structure on snail kites (i.e., if snail densities are very low, kites will do poorly regardless of hydrology or shifts in plant community). For the 30 year period noted, most apple snail field studies included observations of egg clusters (e.g., Gleason et al. 1975, Hanning 1979, Turner 1996) easily observed on plant stems above the water's surface. Gary Hanning's thesis (1979, Florida State University) provided a wealth of information on aspects of Florida apple snail reproduction (including physiological aspects) and patterns of egg cluster production, as well as providing some indication of how apple snails respond to changes in environmental conditions (temperature, water levels). Richard Turner (Florida Institute of Technology) also provided important information on snail eggs, including their development (Turner and McCabe 1990), preference for egg laying substrate (Turner 1996), and the impact of flooding on egg hatch success (Turner 1998). Evidence for a lack of tolerance of apple snails to drying events (Little 1968, Kushlan 1975, Turner 1994) had led the management community in the 1970s-1990s to avoid wetland drying events in support of apple snails and snail kites. However, Darby (1998, dissertation, UF), concluded that earlier assertions of mortality of snails in dry marsh were confounded by an annual post-reproductive die-off of adult snails. Darby et al. (now at UWF) conducted field telemetry studies as well as controlled studies of snails to quantify movements, survival, and recruitment in response to drying events. Darby and colleagues evaluated several sampling protocols, and since 2002, conducted periodic sampling of snails and egg clusters on several central Florida lakes and WCA3A (see details below). Since the establishment of the invasive, exotic apple snail *Pomacea insularum* in Florida, several reports or publications have been released addressing: taxonomic confusion between the exotics *P. insularum* and *P. canaliculata* (Rawlings et al. 2007), the effects of habitat management on exotic snails (Darby 2006), and the potential negative impact of *P. insularum* on snail kites (Darby et al. 2007, Cattau et al. 2010).

Current Protocols and Summary of Sampling Effort

Unlike the snail kite, the Florida apple snail has not been the subject of routine monitoring of population trends. Apple snail densities have been collected in a number of wetlands in a number of years for a variety of objectives (Table 2-1). The wetlands in which the most sampling has occurred are LKISS and WCA3A (Darby 2006, Darby 2008, and Darby et al. 2009, respectively).

Darby et al. (e.g., 1999, 2005) most often use 1 m^2 throw traps to determine snail densities in a particular area. The aluminum throw trap is 60 cm high, and an extension can be used to sample in water up to 100 cm deep. Dip nets are used to extract snails from throw traps, but other extraction

Table 2-1. Locations, years, and numbers of sites for which there are estimates of Florida apple snail densities (snails/m^2). In many sites with density estimates, egg cluster counts were also conducted. Snail sampling was done in emergent marsh habitat unless otherwise noted. Estimates are for snails > 20 mm unless indicated by "juveniles included." "Exotic" refers to estimates of *Pomacea insularum* (for all such sites, only exotics were found). If data were published in both a peer-reviewed manuscript and a contract report, only the peer-reviewed publication is cited.

Sampling Location	Season, Year	No. Sites	Purpose (and additional notes)	Citation (*italics* indicates peer-reviewed publication)
BCWMA	Spring 1996	2	Monitoring	*Darby et al. 2006*
BCWMA	Spring 1996	1	Pilot study of mark-recapture protocol	Darby, unpublished data
BCWMA	Fall 2007	12	Monitoring	Darby 2008
ENP	1966-1971	10	Monitoring (monthly samples in 10 sites, but only one overall average density reported per year)	*Kushlan 1975*
GWP	Spring 2006	3	Kite foraging study	Darby et al. 2009
LISTOK	Spring 2006	8	Monitoring	Darby/McMillian, unpublished data
LISTOK	Spring 2007	3	Monitoring	Darby, unpublished data
LISTOK	Spring 2008	9	Monitoring (pre lake habitat management)	Darby 2009
LISTOK	Spring 2009	6	Monitoring (post lake habitat management)	Darby 2009
LKISS	Fall 1995	7	Compare 1-m^2 data to other sampling methods	*Darby et al. 2004*
LKISS	Fall 2001	4	Monitoring	Darby 2006
LKISS	Fall 2002	4	Monitoring	Darby 2006
LKISS	Fall 2003	4	Monitoring	Darby 2006
LKISS	Fall 2004	4	Monitoring	Darby 2006
LKISS	Fall 2005	4	Monitoring	Darby 2006
LKISS	Fall 2006	6	Monitoring	Darby 2006
LKISS	Spring 2007	9	Monitoring	Darby 2008
LKISS	Fall 2007	2	Monitoring and kite foraging studies	Darby, unpublished data
LKISS	Spring 2008	18	Monitoring and kite foraging studies	Darby, unpublished data
LKISS	Spring 2009	1	Parasite study	Collins et al. 2009
LTOHO	Fall 2001	12	Monitoring (pre habitat management)	Darby 2006
LTOHO	Fall 2002	12	Monitoring (pre habitat management)	Darby 2006
LTOHO	Fall 2003	3	Monitoring (pre habitat management, only exotics observed	Darby 2006
LTOHO	Fall 2004	12	Monitoring (pre habitat management, only exotics observed)	Darby 2006
LTOHO	Fall 2005	8	Monitoring (post habitat management, only exotics observed)	Darby 2006
LTOHO	Spring 2006	4	Monitoring (only exotics observed)	Darby 2006
LTOHO	Spring 2007	4	Monitoring (only exotics observed)	Darby, unpublished data
LTOHO	Fall 2007	2	To estimate snail density prior to vegetation planting	Darby, unpublished data
LTOHO	Spring 2008	4	Snail densities associated with nesting kites	Darby, unpublished data
LTOHO	Spring 2009	3	Parasite study (exotic snails only)	Collins et al. 2009
LOKEE	Spring 2005	6	Monitoring	Darby 2006
LNWR	Spring 2004	3	Monitoring – impoundments	*Darby et al. 2006*
WCA1	Spring 2002	3	Densities in different habitat types	Darby and Karunaratne 2005
WCA1	Spring 2003	3	Densities in different habitat types	Darby and Karunaratne 2005

Table 2-1 ***continued***

Sampling Location	Season Year	No. Sites	Purpose (and any important notes)	Citation (*italics* indicates peer-reviewed publication)
WCA1	Spring 2004	4	Snail densities in historic kite nest areas	*Darby et al. 2006*
WCA2B	1995-1996	4	1-m^2 throw trap protocol development	*Darby et al. 1999*
WCA2B	Spring 2006	3	Monitoring	Darby et al. 2009
WCA3A	Spring 1987	2	Compare densities between kite nesting areas	Bennetts et al. 1988
WCA3A	Spring 1996	3	1-m^2 throw trap protocol development	*Darby et al. 1999*
WCA3A	Spring 1997	6	Mark-recapture protocol development	*Valentine-Darby et al. 2008*
WCA3A	Spring 2002	4	Densities in different habitat types	*Karunaratne et al. 2006*
WCA3A	Spring 2003	5	Densities in different habitat types	*Karunaratne et al. 2006*
WCA3A	Spring 2004	5	Monitoring trends (compared to 2002-2003)	Darby et al. 2005
WCA3A	Spring 2005	6	Monitoring (along hydrologic gradient)	Darby et al. 2009
WCA3A	Spring 2006	6	Monitoring (along hydrologic gradient)	Darby et al. 2009
WCA3A	Spring 2006	2	Kite foraging study	Darby et al. 2009
WCA3A	Spring 2007	2	Monitoring (along hydrologic gradient)	Darby et al. 2009
WCA3A	Spring 2009	4	Monitoring	Darby, unpublished data
WCA3A	Spring 2010	4	Protocol development for kite foraging studies	Darby, unpublished data
WCA3B	Spring 2006	3	Kite foraging study	Darby et al. 2009
WCA3B	Spring 2010	3	Protocol development for kite foraging studies	Darby, unpublished data

methods have also been used (Bennetts et al. 1988, Darby et al. 1999). After trap deployment, the trap is pushed firmly into the substrate to ensure that snails do not escape from the trap. Dominant emergent plants and submerged aquatic vegetation (SAV) are noted, and emergent stems are counted in two ¼-m^2 quadrats within the 1-m^2 trap. Water depths are measured in each trap. Vegetation is removed from the trap and examined for snails. Dip nets of 13-mm mesh netting are used for snail extraction by carefully sweeping them through the trap. If no snails are found in 16 sweeps, then the sampling of the trap is complete. However, if a snail is found in one of the sweeps, then the count starts over again until no snails are captured. The last step is a 30-second hand search wherein the trap is examined for snails missed by dip nets (e.g., in depressions created by uprooting plants). If no snails are found after 40 traps, then throw trapping ceases in the targeted sampling area. If snails are found, between 50 and 100 traps are necessary per site to ensure a reasonable coefficient of variation (CV) ≈20-30%. As this method is labor intensive, a reasonable CV balances time and effort with sampling precision; the number of traps sampled rarely exceeds 100 because of the marginal gains in precision in sites with low snail densities.

In order to adjust for any effects of habitat conditions on the proportion of snails recovered in a sampling site, capture probability is determined by dropping one or more marked snails into a subset of the 1-m^2 traps prior to vegetation removal. The person clearing the trap is unaware of the

presence of marked snails to avoid observer expectancy bias (see Darby et al. 1999). Capture probability is calculated by dividing the number of marked snails found by the number of marked snails placed in the traps. Snail density estimates for a given site or habitat type are adjusted by dividing the average snails captured per m^2 by the average capture probability for the site or habitat.

When sampling was conducted to compare apple snail densities in different habitat types, the ecotone was generally avoided (sampling was done at least one meter away from the ecotone; e.g., see Karunaratne et al. 2006). The rationale for avoiding ecotone sampling was that kites do not forage right at the ecotone (R. Bennetts pers. comm., Darby and Wight, unpublished data), and these studies targeted kite foraging habitats. Consequently, to date there are no data on snail densities along sawgrass-slough or sawgrass-prairie ecotones, which are where the majority of egg clusters are found (Bennetts et al. 1988, Turner 1996, Darby et al. 1999). However, snails frequently move 1 m or more per day (average 14 m per week during the breeding season; Darby et al. 2002, Valentine-Darby et al. 2011), so that eggs found along the ecotone represent those potentially laid by females in wet prairie and slough, as well as those right along the sawgrass ecotone and those from within the sawgrass patches. Darby et al. (2002) and Valentine-Darby et al. (2011) demonstrated this by tracking individual female movements using radio-transmitters. Preliminary data collected via throw traps from Wight and Darby in WCA3A (2012, unpublished) indicate that densities of adult-sized snails in wet prairie are similar to (or slightly higher than) densities within 1 m of the sawgrass ecotone.

In most sites, egg cluster counts are also made along the sawgrass or other ecotone edge bordering the sampling site. A 1-m x 2.5-m pvc frame is flipped end-over-end 20 times along the transect, and within each trap (flip), the number of egg clusters is recorded (Darby et al. 1999). Egg clusters are a sign that snails are present, but cluster counts do not necessarily reflect adult snail abundance. Counts of egg clusters over time in a given area can be used to monitor the temporal pattern of cluster production (Darby et al. 2008). Cluster counts have also been used to indicate specific vegetation (Turner 1996) and general habitat preferences for oviposition that may be affected by water and habitat management (P. Darby, pers. comm.). Assessments so far indicate that egg clusters are not reliable indices of relative snail abundance, but their potential use for this purpose continues to be explored (Darby and Ren 2004).

CONCLUSIONS

Since their listing in 1967, snail kites have been monitored annually, but reported changes in snail kite abundance and shifts in wetland occupancy can be difficult to interpret. No single sampling protocol or analytical approach can answer all of the questions pertinent to the conservation of this

endangered species. There has been a wealth of extremely valuable qualitative and quantitative information on snail kite response to environmental conditions in the past ~40 years. Many aspects of their ecological needs are well understood by the weight of evidence available. However, other questions remain, especially the relative magnitude of the influence of prey availability on snail kite demography. Although many sites in several wetlands have been sampled to estimate snail density (a component of snail availability, which also includes access to the snails), the scale does not reflect the much larger landscape routinely covered by snail kites. Finally, we found that hydrologic metrics used to explain kite and snail ecology (e.g., deviations from long-term average stage data) may be inadequate and require reevaluation. Recommendations to address these and other information needs are presented in Chapters 10 and 11.

CHAPTER 3: OVERVIEW OF THE LIFE HISTORY, ECOLOGY, AND RANGE OF THE SNAIL KITE

INTRODUCTION

The snail kite (*Rostrhamus sociabilis*) is a medium-sized raptor that is found in the U.S. only in peninsular Florida (Sykes 1984). The species' overall range is from Florida, Cuba, and southern Mexico, to northern Argentina (Sykes et al. 1995). There are three subspecies (Amadon 1975); the subspecies found in Florida and Cuba is *R. s. plumbeus*, while *R. s. major*, and *R. s. sociabilis* are found in Central and South America (Sykes et al. 1995). A recent genetic study found that *R. s. plumbeus* has low genetic variation (as has *R. s. major*), and there were no differences between the Florida and Cuba populations of the subspecies (Haas et al. 2009). There has been no evidence of movements of kites between Florida and Cuba (Sykes 1979, Sykes et al. 1995, Bennetts and Kitchens 1997a), but Beissinger et al. (1983) suggested the possibility. Beissinger et al. (1983) searched for Florida-banded kites in Cuba but found none out of approximately 55 birds observed for bands.

When the subspecies in Florida was listed in 1967, it was listed using the common name "Everglade snail kite." Although this name remains in the official USFWS Code of Federal Regulations (USFWS 1999), the official name for the species according to the American Ornithologists' Union became "snail kite" in 1983. We use the name "snail kite" in this document, although we use "snail kite" and "kite" interchangeably throughout the report.

Snail kites in Florida belong to one population that shifts in distribution among a network of wetlands (Beissinger 1995, Bennetts and Kitchens 1997a, Cattau et al. 2009). The snail kite's population and range have declined since the early 1900s, due primarily to widespread wetland drainage and other changes to its habitat (Sykes 1984, Bennetts et al. 1994, Sykes et al. 1995; also see the discussion of habitat alteration at the end of this chapter). The bird was first found in Florida in 1844 by Edward Harris, who collected a male near the headwaters of the Miami River (Sykes 1984). Its distribution in the U.S. was first described by Howell (1932), as discussed in Sykes (1984).

This chapter will summarize life history and basic ecological information on the snail kite, as well as information on its range and population numbers. Details on snail kite responses to changes in hydrology and habitat structure are emphasized in Chapter 5. All information is on *R. s. plumbeus* unless otherwise noted.

PHYSICAL DESCRIPTION

The snail kite is a medium-sized raptor with a slender, long, and down-curved beak (Beissinger 1988). Its talons too are long, slender, and curved. The sexes are dimorphic in color and pattern (Figure 3-1). Males are a blackish, slate gray, and the base of the tail and tail coverts are

Figure 3-1. Adult female snail kite (on left, with extracted snail) and adult male snail kite (on right, with snail in shell). Photos courtesy of Rob Bennetts.

Photo by Rob Bennetts

Photo by Rob Bennetts

white. Females are muted shades of brown, with a lighter brownish forehead and throat; the pattern at the base of the tail is like that in the male. Adult male eye (iris) color is described as brownish red to dark red, and female eye (iris) color is generally orange. The juvenile snail kite is similar in appearance to the female. Adult kites are 43-48 cm (17-19 inches) in length, with a wingspread of about 102 cm (40 inches). Females tend to be larger and heavier than males (Sykes et al. 1995, Valentine-Darby et al. 1997; e.g., average female mass 446.0 g [47.8 SD, n = 29] and average male mass 394.5 g [22.4 SD, n = 29], Valentine-Darby et al. 1997). Juveniles range in mass from about 290-480 g and average 385.8 g (± 45.1 SD, n=32; Valentine-Darby et al. 1997).

DIET

The snail kite in Florida eats apple snails almost exclusively. Its primary prey is the native Florida apple snail (*Pomacea paludosa*; the subject of much of this report), although the non-native *Pomacea diffusa* was recorded as prey on occasion (Takekawa and Beissinger 1983). *Pomacea diffusa* (previously referred to as *P. bridgesii* in Florida; Rawlings et al. 2007) is similar in size to the Florida apple snail and has existed in Florida for decades; its populations remain relatively restricted (i.e., reported in eight counties) and it has been assumed to pose little threat in the U.S. (Rawlings et al. 2007). Note that in this report when we discuss specific species of non-native apple snails we use scientific names rather than common names, because the common names are more easily confused.

Within the last decade, the invasive, exotic *Pomacea insularum* has become a substantial part of the kite's diet on at least one lake in central Florida— LTOHO. *Pomacea insularum*, from Argentina, Brazil, Bolivia, and probably Uruguay and Paraguay, is known to occur in Florida primarily in the center of the state between Tampa and Orlando, with other occurrences near major cities such as Jacksonville and Tallahassee (Rawlings et al. 2007); it has also been found in canals bordering ENP and LNWR (Rawlings et al. 2007). The primary location where snail kites have been observed eating the species is LTOHO, south of Orlando (Darby et al. 2007, Cattau et al. 2010). In the summer of 2011, about 70 kites were observed feeding on the exotic snail at nearby Lake Runnymeade (Zach Welch, FFWCC, pers. comm.). P. Darby (UWF, pers. obs.) also found *P. insularum* under a kite perch in WCA3A in 2011. There are concerns with the kite relying on these exotic snails for food (see details later in this chapter).

Snail kites have also been known to eat *Viviparous* snails, which are small and provide fewer calories than apple snails (Beissinger 1990). Beissinger (1988) observed a kite eating *Viviparus georgianus* for several weeks during a drought in 1982. Reports of non-snail prey of kites in Florida include: small aquatic turtles, such as stinkpots (*Sternotherus odoratus*) and mud turtles (*Kinosternon bauri*; Beissinger 1988, Beissinger 1990, P. Darby pers. comm.), a rice rat (*Oryzomys* sp.) or cotton

rat (*Sigmodon* sp.; Beissinger 1988), crayfish (*Procambarus* sp.) and speckled perch (*Pomoxis nigromaculatus*; Bennetts et al. 1994), and a ring-necked snake (*Diadophis punctatus*; Sykes 1979). Beissinger (1988) also reported kites eating cooters (*Chrysemys floridana*), red-bellied turtles (*Chrysemys nelsoni*), and soft-shelled turtles (*Trionyx ferox*), all with carapace length 30-90 mm. A few researchers have attributed a switch to non-*Pomacea* foods in Florida as a response to the unavailability of apple snails, such as during drought conditions or the passage of winter cold fronts (Sykes and Kale 1974, Beissinger 1990). Out of 2,712 prey captures observed in WCA3A, WCA2B, LKISS, and LTOHO, 99.4% were *Pomacea* snails (Cattau et al. 2010); non-snail prey during these observations were all small turtles of unidentified species. Beissinger (1990) reported that although the head and forelegs of turtles were often consumed, it was more common for snail kites to consume only one of the rear legs. As a kite holds a turtle upside down on its perch, the shell opening around the turtle's rear leg resembles the shape of a snail's aperture (Beissinger 1988, 1990; Figure 3-2). Handling time for these small turtles may exceed 60 minutes (Beissinger 1990), compared to an average of 2.7 ± 1.4 (SD) minutes (Sykes 1987c) to consume a snail. In May-June of 2007, one male snail kite was observed catching crayfish at a crayfish farm just south of Rimini, South Carolina (along Lake Marion, roughly in between Charleston and Columbia) (Cape Romain Bird Observatory 2007; pictures available on website). The bird was sighted in South Carolina at a time when south Florida wetlands were experiencing dry conditions and wildfires. Bennetts et al. (1994) also reported snail kites feeding on crayfish (*Procambarus* sp.) in Florida.

FORAGING

Habitat

Snail kites forage for snails in wetland habitats that are relatively shallow and vegetated with low-profile emergent plants intermixed with open water (Sykes et al. 1995). Common foraging habitats include wet prairies, lake littoral zones, ephemeral wetlands, river banks, and some man-made canals and agricultural ponds (Sykes et al. 1995). Sykes (1979) described most foraging as occurring over shallow (0.2-1.3 m) sloughs of white water-lily (*Nymphaea odorata*) and wet prairies or flats of spikerush (*Eleocharis elongata* and *E. cellulosa*). Freshwater marshes inhabited by the kite also generally have scattered shrubs or small, low trees (e.g., willow ([*Salix* sp.], wax myrtle [*Myrica cerifera*], and pond apple [*Annona glabra*]) that may be used as perches.

Snail kites are visual hunters and capture snails when they come to the surface to respire or are resting or moving on plants near the surface (Bennetts et al. 1994, Sykes et al. 1995). Kites only forage over flooded marsh and are unable to access apple snails in dry down conditions (Sykes 1979). Sykes' (1979) reported foraging depth of 0.2 to 1.3 m came from observations of approximately

Figure 3-2. Portion of a turtle eaten by a snail kite (left panel), compared to the aperture of an apple snail shell (from which a kite extracted the snail flesh). Photo courtesy of Rob Bennetts (the single photo was split in two to better show shape similarity).

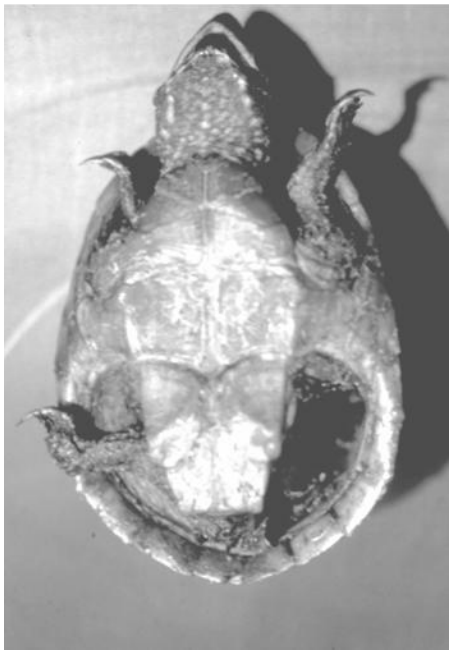


Photo by Rob Bennetts

2,000 kite foraging bouts. While sampling snails on LKISS, however, snail kites were observed capturing snails in less than 10 cm of water at the lake's edge (Dave Mellow, UWF, pers. comm.). Because kites must see snails at or near the water's surface, vegetation (or any other structure) that reduces visibility of the water's surface will negatively impact foraging. Snail kites prefer relatively low plant density areas for foraging (Bennetts et al. 2006) and do not forage over dense habitats such as dense sawgrass or cattail, or where floating vegetation (e.g., water hyacinth [*Eichhornia crassipes*] or water lettuce [*Pistia stratiotes*]) blankets the surface (Sykes 1987b). Sykes (1987b) also suggested that floating periphyton mats "block portions of foraging patches," but the degree to which this may be an issue has not been addressed. Based on a simplistic imagery classification (R. Bennetts Comment Matrix, Comment #15, Appendix B), Bennetts et al. (1988) estimated suitable foraging habitat in a portion of WCA3A as approximately 30-40% open water mixed with emergent vegetation. The vast majority (approximately 97%) of foraging bouts observed by Sykes (1987b) were over wetland habitats with relatively open water and scattered emergent and/or floating vegetation (e.g., floating *Utricularia*-periphyton complexes). Additional information on the influence of vegetation structure and density on snail kite foraging is provided in Chapter 5.

Types of Foraging

This section presents basic information on how kites forage. Additional information regarding influences on foraging affected by management (water and habitat structure), and how prey density affects foraging, are presented in Chapters 5 and 7.

Snail kites exhibit two modes of foraging (Snyder and Snyder 1969, Sykes 1987b)— aerial (or "course") hunting and perch (or "still") hunting. In both foraging modes, the kite flies down to the water surface to grab the snail in its talons, often transferring the snail to its bill during flight (Snyder and Snyder 1969). Snails can be captured at a maximum of about 16 cm below the water surface (the approximate length of extended legs and feet), although snails are usually captured within the top few cm of the water column (Sykes et al. 1995). The defense of foraging patches is rare, and several snail kites may forage over a patch and sometimes share a feeding perch (although not at the same time; Sykes 1987b).

<u>Perch hunting</u>

Perch hunting consists of a snail kite perching on 0.15-4.6-m-high (0.5-15-ft-high; average=2.0 m [6.6ft]), most often woody, vegetation over the edge of an open slough/open water or wet prairie habitat (Sykes 1987b). Kites tend to perch with the brightest light towards their back, in an upright position, while scanning the water below for snails (Sykes 1987b). Snail captures are

made within about 0.9-12.2 m (3.0-40 ft; average=5.8 m [19ft]) of the perch (Sykes 1987b), depending on the height of the perch (increased distance with higher perches; Holgerson 1967). Captured snails are brought back to the same or a different perch where they are extracted and consumed (Snyder and Snyder 1969, Sykes 1987b). Perch hunting may be limited by the availability of suitable perches (Sykes 1987b). In Guyana, South America, perch hunting was nearly as common as course hunting, probably because of the availability of perches (Snyder and Snyder 1969, Beissinger 1983). In Guyana, when the water's surface became obstructed or there was no suitable foraging habitat near a perch, kites shifted to course hunting (Beissinger 1983). In a Florida study including 814 prey captures, perch hunting accounted for 143, or 18% of the captures (Valentine-Darby et al. 1998). Perch hunting was used mostly in cypress prairie habitats (which occurred primarily in western WCA3A, BCNP, and portions of the Loxahatchee Slough), where perches were more readily available.

Course hunting

Snail kites in Florida most often use course hunting (Snyder and Snyder 1969). Course hunting involves slow wing beats and gliding 1.5-3 m (4.9-9.8 ft) over the marsh with the head tilted down in search of snails (Sykes 1987b, Bennetts et al. 1994). Kites usually fly into the wind, or quarter the wind, when course hunting (Sykes 1987b). Mahoney et al. (2010) found that snail kites avoided snails (available as bait set in floating trays) if their capture required flying with the wind. However, when snails/floating trays were located upwind from the same perched kites, kites readily flew to the snails in the trays. Sykes noted that foraging flights were slower than all other flights for snail kites (Sykes 1987b); flying more slowly, into the wind, may allow more effective scanning, and therefore detectability, of snails near the surface. The time required to capture a snail while course hunting is inversely related to snail density (see Chapter 7).

Environmental Influences on Foraging

As previously mentioned, Chapter 5 includes a discussion of the influence of vegetation structure and density on snail kite foraging. Here, we discuss foraging influences that are independent of management— temperature and wind.

Cold temperatures reduce apple snail activity, and, consequently, movements that would bring snails to the surface where they are vulnerable to snail kites. Stevens et al. (2002) found that no snails were active in water <13 °C, and that most (92%) snails burrowed into the sediment in temperatures <10 °C. In field studies in south Florida, Cary (1985) observed no snail kites capturing apple snails when temperatures dropped below 10°C, and an almost linear increase in captures as

temperatures increased from 11°C to 30°C. Reduced snail activity may also explain why kites begin foraging later in the day in colder months (November-March; Sykes 1987b). Temperature may also influence the seasonal distribution of snail kites and be a major factor limiting the northern extent of the kite's range (Stevens et al. 2002).

As temperature increases, dissolved oxygen decreases and *Pomacea* snails surface more frequently to breathe air (McClary 1964); they then become more available to kites. However, high temperatures may also thermally stress snail kites. In temperatures > 32°C (90°F), kites often perch with wings spread and pant in what appears to be an effort to cool off (P. Darby, UWF, pers. obs.). In spring and summer in Florida, kites typically begin foraging about 30 minutes after sunrise and end foraging about 30 minutes before sunset (Sykes 1987b). Although they forage throughout the day (Sykes 1987c, Cattau et al. 2010), a lull in activity of individual kites may occur between 10:00 am and 3:00 pm (Sykes 1987b). Studies in Guyana, South America, showed a stronger tendency for a lull in activity (Beissinger 1983). Peaks in foraging profitability occurred in the early morning and late afternoon; a lull in the mid afternoon may have been related to thermal stress (Bourne 1985a). An increase in perch hunting was also observed during this time period (Beissinger 1983). Less frequent foraging in high temperatures may also be related to an increase in energy requirements for flight as air temperature increases (warmer temperatures create less dense air which provides less lift for flight; Beissinger 1983).

Wind may also affect snail kite foraging. Moderate to high wind causes ripples on the water surface that may impede visual detection of snails in the water column (P. Darby, UWF, pers. obs.). Kites were observed foraging on the more sheltered side of Ox Island on LKISS when winds were >15 mi/hr, even though snail densities were higher on the other side of the island (D. Mellow, UWF, pers. obs.). As the winds declined or shifted, the kites were observed moving to the higher-prey-density side of the island.

Foraging Success, and Capture Times and Rates

Sykes (1987b) recorded about 2,000 foraging bouts between November and early July in south Florida to estimate success (proportion of foraging bouts resulting in successful captures) and capture times (average time to successfully capture a snail). A course-hunting foraging bout began when the bird left a perch and ended when the bird returned to a perch with or without a snail. A perch-hunting bout started when the bird obviously began searching the water (with head oriented downward), and it ended when the bird returned to a perch after attempting to capture a snail. Capture times included time flying back to the perch with a snail, but not prey handling time. Females' hunting bouts were longer than males' (2.5 minutes [SD=2.9] compared to 1.2 minutes

[SD=1.2]). However, females were more successful in course-hunting than males (70% success rate for females compared to 48% for males); no such significant difference was observed with perch hunting. In comparison, Cattau et al. (2010) observed no gender differences and an average capture time of 1.5 minutes. Beissinger (1983) reported that about 80% of foraging bouts in Guyana were successful, and Darby et al. (2012) observed a success rate of 89% (140 successful out of 158 bouts) for snail kites in Florida. Reported capture rates ranged from 1.7-3.4 snails per hour with a mean of 2.5 (SD=0.48; Sykes 1987b). Of the studies mentioned here, none except Darby et al. (2012) had concurrent information on apple snail densities; see Chapter 7 for a discussion of how snail density influences snail kite foraging times. Total number of snails consumed per day has not been reported, but it can be estimated with the use of other information (see Chapter 7 for estimates).

Prey Handling

After capturing an apple snail, a snail kite takes the snail to a feeding perch to process it. The kite positions the snail with the aperture facing up (Sykes et al. 1995). The operculum is removed and discarded. The kite then inserts its sharply-hooked upper mandible into the shell to cut the columellar muscle that connects the snail to the shell, thereby freeing the soft tissue (Snyder and Snyder 1969). The snail tissue is eaten in small chunks or whole (Snyder and Snyder 1969). Snail kites often remove the albumen glands of female apple snails before consumption (Sykes 1987b). Snyder and Snyder (1971) described the albumen gland as having an unpleasant taste, the same bitter taste associated with apple snail eggs. [More recent work has identified the chemical compounds associated with the bitter taste (e.g., see Dreon et al. 2010)]. The empty shells are discarded below the perch, with minimal damage and only minor chips on the edge of the aperture (Snyder and Snyder 1969).

Food handling times are an important component of energy or calorie balance for predators (e.g., Cattau et al. 2010). Sykes (1987b) reported prey handling times, measured from the time the snail kite arrived at a perch through the time the snail was ingested. Prey handling time ranged from 1-7 minutes, with an average of 2.7 minutes (SD=1.4), and there was no significant difference between male and female kites. Somewhat shorter average handling times have also been reported (1.3 minutes for adult kites and 2.1 minutes for juvenile kites; Cattau et al. 2010). Cattau et al. (2010) also reported significantly greater handling times for both adult and juvenile snail kites eating the relatively larger, non-native snail *Pomacea insularum* (5.8 minutes and 8.4 minutes on average, respectively).

Snail Sizes Consumed

Few data exist addressing whether snail kites select particular-sized snails for capture, and whether captured prey reflected the size proportion of snails available. Florida apple snails hatch at about 3-5 mm in diameter, reach sexual maturity at a size of approximately 25-30 mm shell length, and rarely exceed 50 mm (Hanning 1979, Darby unpublished data). Snail size distribution shifts seasonally, as recruitment of smaller individuals occurs in spring-summer and an annual die-off of adults follows the peak egg-laying season (Hanning 1979, Darby et al. 2008). Snail "selection" implies that kites can visually assess what size ranges are available and choose to consume snails in a certain size range. The main obstacle in quantifying selection lies in the difficulty of sampling the snail population to determine the size distribution of available snails. This cannot be ascertained from collecting snails under a kite perch, because that does not indicate the sizes of snails available in the foraging habitat. There is also no evidence that snail kites can detect juvenile-sized snails but choose not to consume them (as distinguished from the inability to see smaller snails). A kite may also be unable to grasp a small snail in its talons should it attempt to capture one.

Beissinger et al. (1994), citing Bourne (1985b) and Beissinger's unpublished data, noted that snail kites tended to select the largest snails first from feeding trays, but they did not provide details on the snail sizes or species offered. Sykes (1987b) reported that all apple snails consumed by snail kites using 13 feeding perches in Florida were > 20mm in shell length (range = 25.2-71.3 mm, average = 42.8 mm [SD = 4.9, n = 697]). Shell lengths of 30-60 mm accounted for 98.5% of discarded shells found under kite perches (Sykes 1987b). Sykes also collected live snails from the field, but size-frequency distributions of the sample snail population were not reported.

Beissinger (1983) estimated the preferred size classes of snails (99% of which were *Pomacea doliodes*) eaten by snail kites in Guyana. Size classes were based on ***aperture*** lengths (small = 11-24 mm; medium = 24-28 mm; and large = 29-36 mm) of empty shells found under kite perches. He then estimated the relative abundance of the different snail size classes potentially available to kites by walking and crawling transects through the fields and feeling for snails; of 155 snails, 53% were small, 31% were medium, and 16% were large. Of the snails found under kite perches, 43% were small, 43% were medium, and 14% were large. Although a substantial portion of the consumed snails were small, snail kites exhibited a slight tendency to avoid smaller snails in favor of medium-sized snails. Snail kites ate the largest snails in approximate proportion to their availability. Beissinger (1983) pointed out that the method used to collect the live snails assumed that all sizes of snails were equally collectable, which may not have been the case.

Although Beissinger (1983) found no upper size limit on snails (this idea was not tested), other studies do indicate an upper limit for prey captures. In a study in Venezuela, where kites

usually consume *Pomacea doliodes*, wild, free-flying snail kites were offered *P. urceus* (which they were not known to eat) in feeding trays (Beissinger et al. 1994). Five of the dozen kites tested did not take the *P. urceus* offered. Of 12 of the *P. urceus* picked up by kites, 8 were dropped almost immediately, while the remaining 4 snails were consumed. The size of *P. doliodes* found under kite perches in the study area ranged from 30-70 mm shell length, while the sizes of *P. urceus* offered were 50-110 mm in shell length. The exact sizes of the 4 snails eaten and 8 snails dropped (i.e., within the 50-110 mm range) were not reported.

Starting around 2003, snail kites were observed feeding on *P. insularum* (Cattau et al. 2010), an invasive non-native snail, on LTOHO, where the native snail abundance was very low (Darby 2006). *P. insularum* adults (often > 90 mm shell length) are much larger than *P. paludosa* (typically 30-45 mm in length, and rarely exceeding 60 mm shell length; Hanning 1979, Sykes 1987b, Darby et al. 2007) (see Figure 3-3). Darby et al. (2007) observed a 44% drop rate on LTOHO by snail kites capturing non-native snails, compared to drop rates of 1% (Cary 1985, Sykes et al. 1995) and 0% (during their own observations, n=136) for kites during native snail captures. The sizes of *P. insularum* shells found under kite perches on LTOHO were similar to those of live snails captured in throw traps on the lake; average shell width was 81 ± 6 mm (SD), and estimated lengths averaged 95 ± 7 mm (SD) (Darby et al. 2007). The smallest *P. insularum* shell found was 77 mm in length. Cattau et al. (2010), who conducted a longer (multiple year) study of snail kites foraging on *P. insularum*, measured shell lengths only from under kite perches; the average shell size reported was 63.5 ± 0.4 mm (n=1,486). The snail size difference reported in the two studies may have been because, over time, as the invasive snail expanded and reproduced on the lake, more snails smaller in size (younger) were present in the population, and therefore available to kites. Cattau et al. (2010) reported 39.3% of exotic snails dropped by juvenile kites and 21.5% of exotics dropped by adults (compared to drop rates of 5.5% for juveniles and 2.4% for adults capturing the native snail).

Snail kites may have an inherent mechanical limitation in capturing/eating the larger, exotic snails due to talon size (i.e., the larger, non-native snails may simply be more difficult for a kite to grasp; Darby et al. 2007). Also, the increased weight of the snail, compared to the native, may pose difficulties in handling (Darby et al. 2007, Cattau et al. 2010). It was first thought that the higher handling costs might be outweighed by the greater caloric yield from eating the larger, exotic snails, and indeed, adult snail kites appear to survive on the exotic snail. However, Cattau et al. (2010) found that there were significant energetic deficiencies for juvenile kites foraging on *P. insularum*. The gross daily energetic gains for kites feeding on exotic snails were calculated as 140 ± 4 and 97 ± 7 kcal/day for adult and juvenile kites, respectively, while those for native snails were 167 ± 5 and 175 ± 7 kcal/day for adult and juvenile kites, respectively (Cattau et al. 2010). The significantly

Figure 3-3. Typical adult-sized exotic channeled apple snail, *Pomacea insularum*, found on LTOHO (81 mm total width x 93 mm total length), and typical adult-sized Florida apple snail, *P. paludosa*, found on LKISS (31 mm total width x 34 mm total length), as reported by Darby et al. (2007). The *P. insularum* specimen represented typical size consumed (and often dropped) by snail kites on LTOHO, as reported in Darby et al. (2007). Photo from Darby et al. (2007), used with kind permission from the Florida Ornithological Society: Florida Field Naturalist, Food-handling difficulties for snail kites capturing non-native apple snails, Volume 35, 2007, Pages 79-85, P.C. Darby, D.J. Mellow, and M.L Watford, Figure 1, bottom panel.

Pomacea insularum *Pomacea paludosa*

lower net daily energy balances for juvenile snail kites feeding on exotic apple snails may result in overall net losses of energy for juvenile kites. In 2008 on LTOHO, three emaciated juvenile kite carcasses were found, with starvation the cause of death in all three cases (Cattau et al. 2010). At the same time, partially eaten exotic snails were found under feeding perches and in nests; it is not clear if emaciation was due to lack of suitable prey, handling difficulties, or juvenile inexperience (Cattau et al. 2010). [See Cattau et al. (2010) and Chapter 7 of this document for other aspects of foraging energetics, including calorie content of exotic and native snails].

NESTING

Snail kites usually nest in areas in close proximity to foraging habitat (described above) that offer nest sites over water (details below). Snail kites nest in solitary pairs or in colonies, often in association with anhingas (*Anhinga anhinga*), herons, or ibis (Sykes et al. 1995). In mixed colonies, kites tend to nest on the outer edge of the colony. Nest sites may be highly visible or well hidden, but they are usually open from above for easy access to the nest (Beissinger 1988).

Nesting Substrates

Snail kites use small trees (usually less than 10 m tall), shrubs, or herbaceous vegetation for nesting substrates (various sources cited in Sykes et al. 1995). Tree species used include coastal-plain willow (*Salix caroliniana*), bald cypress (*Taxodium distichum*), pond cypress (*Taxodium ascendens*), punk-tree or melaleuca (*Melaleuca quinquenervia*), sweet bay (*Magnolia virginiana*), red bay (*Persea borbonia*), dahoon holly (*Ilex cassine*), and pond apple. Shrub species include wax myrtle, buttonbush (*Cephalanthus occidentalis*), cocoplum (*Chrysobalanus icaco*), rattle-bush (*Sesbania* sp.), elderberry (*Sambucus canadensis*), and Brazilian pepper (*Schinus terebinthifolius*). Herbaceous species include sawgrass (*Cladium jamaicense*), cattail (*Typha* spp.), bulrush (*Scirpus* spp. [some species now in the genus *Schoenoplectus*]), and reed (genus and/or species not provided). Nests in woody vegetation may occur individually in isolated woody shrubs on mounds in the marsh, or communally in shrub strands or “tree islands” (Kitchens et al. 2002).

Willow reportedly provides the most shelter from sun, wind, and rain (Sykes 1987a). Nests in woody vegetation are more stable (and therefore less likely to collapse) than those built in herbaceous vegetation (Sykes and Chandler 1974, Sykes et al. 1995), and higher nest success has been reported for nests in woody vegetation (e.g., Snyder et al. 1989a). In his study of almost 400 nests, Sykes (1987a) found that willow stands were used most often for nesting. Bennetts et al. (1988) found that willow was the most often used nest substrate in WCA3A (45% of 375 nests; followed by pond apple, cypress, melaleuca, and wax myrtle), but that pond apple and melaleuca

were used more than expected based on their availability. Of nearly 200 nests in WCA2B, all were in either melaleuca or willow, with melaleuca being the most frequently used (75% of nests; Bennetts and Kitchens 1996a). The authors did not provide data on the relative abundance of these two species. Willow was also the most used woody substrate for nests monitored by Snyder et al. (1989a) in WCA3A and on LOKEE, LKISS, and LTOHO (n=189). In the Blue Cypress Water Management Area (BCWMA), cabbage palm (*Sabal palmetto*) has been used for nesting in addition to willow and cypress (Dreitz et al. 1999).

A number of authors reported regional differences in the relative use of woody versus non woody-stemmed plants. Sykes (1987a) reported 98% of nests were built in woody vegetation in the Everglades, 81% in the St. Johns area, and 49% at LOKEE. Cattau et al. (2007) reported (for nests monitored in 1995-2004) 97% in woody substrates (and 3% herbaceous) in the Everglades region, 30% in woody substrates (and 70% herbaceous) in the Kissimmee Chain-of-Lakes, 77% in woody substrates (and 23% herbaceous) in the St. Johns Marsh, and 83% in woody substrates (and 17% herbaceous) at LOKEE. Snail kites nesting on the lakes in central Florida frequently use cattail or bulrush (*Scirpus californicus or validus* [now *Schoenoplectus californicus* and *S. tabernaemontani*, respectively]) as nesting substrates (Snyder et al. 1989a, Rodgers 1992, Rodgers 1998), probably because of a lack of woody vegetation (Bennetts et al. 1994). Available woody vegetation in these areas tends to be in close proximity to upland areas, which increases the risk of predation (Beissinger 1986, Sykes 1987a). Therefore, kites on the central Florida lakes nest mostly in non-woody vegetation during lower water levels (Rodgers 1998), and tend to use woody vegetation only in years with higher water when the sites with woody vegetation are flooded (Beissinger 1986).

Nests have been reported as usually occurring 1 to 5 m (3.3-16.4 ft) above the water (Beissinger 1988) and averaging 1.6 m (n=99; Sykes 1987a) or 2.0-3.6 m (Dreitz et al. 1999) above the water. Bennetts et al. (1988) reported the height of nests above the ground (not water) surface; nests ranged in height from 0.9 to 12.4 m (3 to 41 ft) above ground level.

Water Depths under Nests

As noted previously, snail kites nest over water for protection from terrestrial predators (Beissinger 1984, Sykes 1987a). In addition to increasing the threat of predation, the drying out of an area would also make apple snails unavailable to nesting kites (Bennetts et al. 1994). Water depths may fluctuate considerably during the breeding season (Sykes et al. 1995, Bennetts and Kitchens 1996a). Sykes (1987a) reported water depths beneath nests ranging from 12-115 cm (mean = 52, SE = 1.8, n = 139). Bennetts et al. (1988) reported water depths at nest sites ranging from 20-80 cm (94% of 281 nests) in the Everglades (WCA3A) at the time the first egg at each nest was laid (1986

average depth under nests = 41 cm, and that in 1987 = 50 cm). Schortemeyer (1980) suggested water depths similar to those reported by Bennetts et al. (1988) and Sykes (1987a) (i.e., those discussed above) were optimal for kites (Bennetts et al. 1988). An atypically high average water depth under nests in WCA2B in 1995 was 91 cm (26.0 SD), probably due to a tropical storm-induced extreme high water event (Bennetts and Kitchens 1996a, Bennetts et al. 2002). An average depth of 60 cm ± 27.0 (SD) (at the time of nest initiation) was reported for nests (n = 745) throughout the snail kite's range in 1988-1995 (as reported in Dreitz and Kitchens 1996; this figure includes some of the data already mentioned [e.g., from Bennetts et al. 1988]). Monitoring of nests in BCWMA has shown similar water depths (53-78 cm; Dreitz et al. 1999).

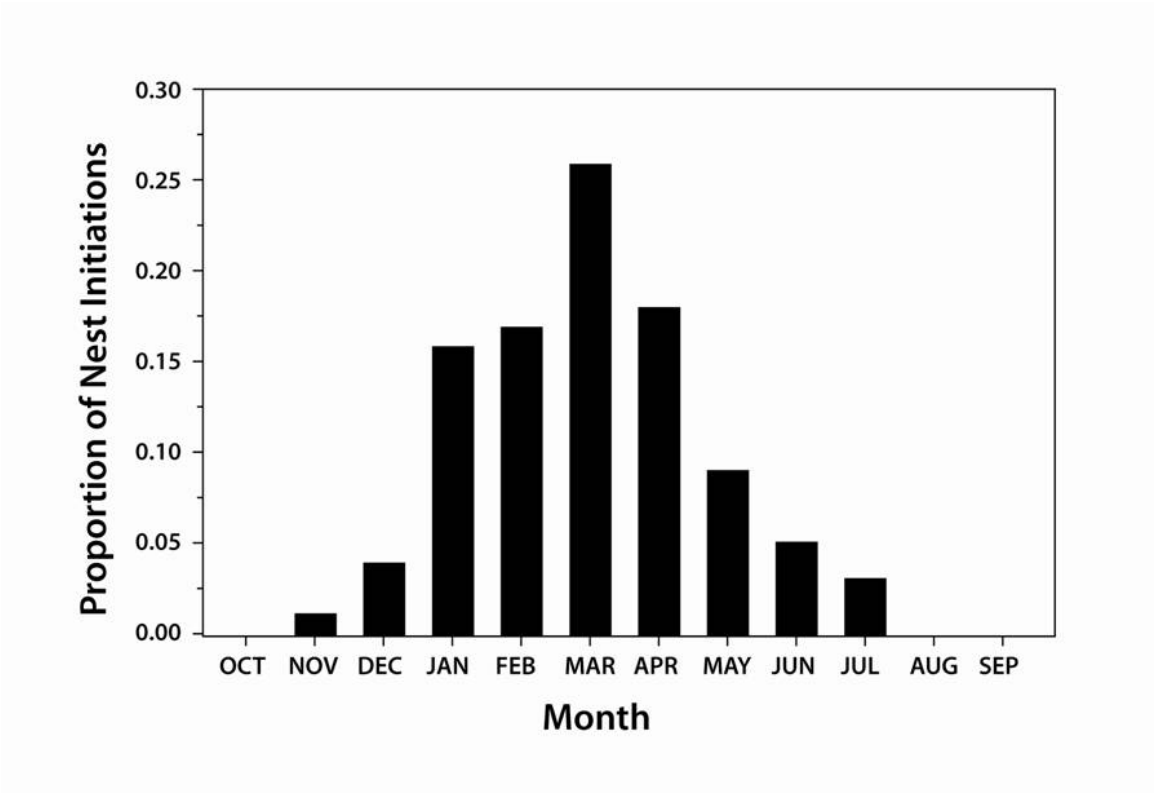
The Bennetts et al. (1988) study found that only 3% of kite nests were built in a location with less than 20 cm of water. Significantly lower nest success was not observed in areas with less than 25 cm water depths, but none of the nesting areas dried out completely during the study. From this work, the authors suggested that 20 cm was the minimum water depth for suitable snail kite nesting habitat, but they emphasized that this minimum depth was only for habitat in the Everglades—suitable water depths in lake habitats may be different. Additionally, although they found few nests in water depths greater than 80 cm, they pointed out that nests may be found in deeper water in different years or under different conditions (e.g., in lake habitats or in WCA2B in 1995). They also suggested that close access to foraging areas probably played an important role in the selection of the deeper nesting sites.

Additional information related to this topic, such as the influence of water levels on nesting success, is discussed in Chapter 5. Also, information on trends in the use of lake and wetland units for nesting is addressed in various chapters of this document.

Nesting Season, Clutch Size, and Young Produced

The timing of the snail kite nesting season in Florida varies. In general, female kites begin to lay eggs 10-30 days after the start of courtship and nest building activities (Sykes 1987c). Egg-laying has been documented in all months of the year (Sykes 1987c), but the primary nesting season is generally January to June (89% of nesting attempts; Sykes et al. 1995; Figure 3-4). The peak in egg-laying may occur several weeks later in the northern portions of the kite's range (Toland 1994). Sykes (1987c) reported that peak egg-laying generally occurred 81 days (95% CI = 61-101 days) before the onset of the rainy season in middle to late May. Variation in the breeding season from year to year depends on rainfall and water levels (Sykes et al. 1995), and it may last for eight months or

Figure 3-4. The proportion of nest initiations (i.e., nests with eggs) for each month of the year based on data from Sykes (1987a), Snyder et al. (1989a; 1970-1982 only), Toland (1994), and Bennetts and Kitchens (1997a), as reported in Bennetts and Kitchens 1997a. Used by permission of R. Bennetts.



more in the presence of favorable water conditions and abundant food resources (Sykes 1987c, Beissinger 1988, Snyder et al. 1989a, Sykes et al. 1995).

Clutch size ranges from 1 to 6 eggs and averages 3 (Nicholson 1926, Howell 1932, Bent 1937, Sykes 1987c, Beissinger 1988, Snyder et al. 1989a, Sykes et al. 1995). More common in the early 1900s, clutches of 4 and 5 eggs are now rare (Chandler and Anderson 1974, Beissinger 1986 and 1988, Sykes 1987c, Snyder et al. 1989a, Sykes et al. 1995, Dreitz and Shannon 1998). Of 560 nests monitored from 1987-1993 on LKISS and LOKEE, 75% of the nests contained 3 eggs, 21.4% contained 2 eggs, 2.3% contained 4 eggs, 0.9% contained 1 egg, and 0.2% contained 5 eggs (Rodgers 2007). One group of researchers reported that clutch size was not affected by annual changes in water levels, seasons, or colonial vs. solitary nesting, but clutch size was larger on LOKEE, LKISS, and LTOHO compared to WCA3A (Snyder et al. 1989a, Sykes et al. 1995).

Males carry out most of the nest-building duties, including courtship feeding, while both males and females share incubation duties (Beissinger and Snyder 1987). The incubation period in Florida ranges from 24 to 30 days (Sykes et al. 1995). Hatching success at several major snail kite habitats from 1968-1978 was 57.5% (Sykes 1987c), and that reported in a separate study at LOKEE was 53.7% (Chandler and Anderson 1974). The nestling period (defined as the period extending from hatching to fledging) reported by Sykes (1987c) averaged 28.7 days and ranged from 23-34 days. Parents generally contribute to feeding nestlings equally, and the time between feedings reported by Sykes (1987b) was 0.5-124 minutes, with an average of 22.3 minutes (n=267). Adult snail kites usually feed their young extracted snails, with viscera removed, bill to bill. When young are about 18-20 days old, some adults bring them whole snails, extracted or in the shell (Sykes 1987b).

A successful nest is one in which at least one chick fledged (e.g., Steenhof 1987, Sykes et al. 1995). There is substantial variability in nest success among different locations, years, and local nest environments (Sykes et al. 1995, Bennetts and Kitchens 1997a). Factors that may affect the outcome of nests include (but are not limited to) location, water levels, nesting substrate (e.g., woody vs. herbaceous substrates), date of nest initiation, and nest height (various authors, as reviewed in Bennetts and Kitchens 1997a).

The **number of young** per successful nest is one of the least variable and least controversial reproductive parameters (Bennetts and Kitchens 1997a). Sykes (1987c) reported an average of 2.0 (range 1.4-2.5) young per successful nest in 1968-1978; Snyder et al. (1989a) reported an estimate of 1.96 for the period 1966-1983; Beissinger (1986) reported an estimate of 2.0 for the years 1979, 1982, and 1983; and Bennetts et al. (1988) reported an estimate of 1.44 and 1.65 in WCA3A for 1986 and 1987, respectively.

There has been some disagreement among researchers about how to determine nest success (Bennetts and Kitchens 1997a). The main areas of dissention were regarding which nests to include/exclude in their datasets and the estimator that should be used to estimate success. Bennetts and Kitchens (1997a) discussed this topic at length (see pages 52-55; they also summarized the literature through 1997 on nest success). The questions surrounding which nests to include or exclude arose because: 1) the probability of success of a nest is influenced by the stage of the nest when monitoring begins (i.e., those found early in the nesting cycle have a lower probability of success than those found late in the nesting cycle); 2) nests at different stages are vulnerable to different risks; and 3) some researchers included nests prior to eggs having been laid (and some of the nests would never have eggs laid in them), while others included only nests containing at least one egg (Bennetts and Kitchens 1997a). When we report nest success (e.g., Chapters 5 and 9), we will point out the methods used to estimate success when possible.

The type of pair bond formed between snail kites is referred to as sequential monogamy, and the kite mating system is called ambisexual mate desertion. In Florida it was reported that 78% of nests (n=36 nests, 1979-1983) showed mate desertion (Beissinger and Snyder 1987). Mate desertion may occur if adequate food resources are available, with either the male or female deserting. Desertion tends to occur about one week before the young fledge, when oldest chicks are about 29 days old (range = 15-53 days; Beissinger and Snyder 1987). The remaining parent cares for the young for an additional 3-5 weeks, usually successfully. When snail resources appear inadequate, kites do not desert, and both parents continue to care for the young. Mate desertion functions to allow deserting kites an opportunity to start new nesting cycles while their mates finish raising the offspring alone (Beissinger 1988). Ambisexual mate desertion is an important adaption because it allows snail kites the opportunity to produce more offspring (than they would if they did not desert) when conditions are good (Beissinger 1986).

Nesting Distribution

Over the period 1968-1980, the primary nesting areas for the snail kite were WCA3A, LOKEE, and WCA2A (Beissinger and Takekawa 1983, Sykes 1984), with the first two sites being used the most during those years (Sykes 1984). On WCA3A during those years, nesting was primarily in the vicinity of the southern/lower half of the L-67A canal, in Dade County. Sykes (1984) described most nesting as occurring 4.5 km north of the Tamiami Trail in the southeast corner of the WCA and extending northeastward along the L-67A canal for about 9.5 km; the nesting area extended up to 4 km west of the canal (also see Figure 5-3 in Chapter 5). Three other very small nesting locations in WCA3A were noted, one just north of the Tamiami Trail and two in Broward

County (eastern half of the WCA and south of Alligator Alley). On LOKEE, the majority of nests were found in the marshes on the west side of the lake. No nesting was recorded in WCA3B or ENP during those years (1968-1980; Sykes 1984). Kites were also known to nest in other areas, including (but not limited to) the headwaters of the St. Johns River and LNWR (Sykes 1984, Beissinger and Takekawa 1983). Dry marsh conditions in WCA3A and WCA2 in 1981-1982 and LOKEE in 1982-1983 led kites to disperse to other areas, and they nested on LTOHO and LKISS in 1982 (Beissinger and Snyder 1987). Beissinger and Takekawa (1983) wrote that these were the first records of breeding on the two lakes, but Rodgers (1992) described nesting on the lakes as the kite reclaiming portions of its former range.

No one source is available to summarize the main nesting areas of the snail kite (and their relative use) from around 1983 to 1995. However, multiple reports and publications note or describe nesting in various wetlands in various years (e.g., Bennetts et al. [1988; WCA3A in 1986-1987]; Toland [1994; SJM in 1990-1993]; Bennetts and Kitchens [1997a; a number of wetlands in both central and south Florida in 1992-1995]; and Rodgers [1992; most main areas in the kite's range from 1986-1992]). Toland (1994) showed the importance of the SJM as part of the snail kite's habitat network. Between 1990 and 1993, up to 140 kites were documented using the BCMCA/BCWMA each year, and there were 26-59 active nests (nests containing at least one egg) annually. In 1992, at least 68 young were fledged. Note that around the same time (1992), Bennetts et al. (2002) found relatively few successful nests (i.e., 36) in the Everglades region (one year after prolonged dry down conditions there). Rodgers (1992) described shifts in the use of some of the wetlands in the snail kite's range for nesting, such as the continued increase in the middle 1980s and 1990s in the use of LKISS, LTOHO, and East LTOHO in central Florida.

Snail kite nest monitoring from 1996-2011 (W. Kitchens, Principal Investigator) indicated that the greatest numbers of active nests throughout the snail kite's range were in WCA3A in 1996-2000, 2002-2004, and 2006 (Table 3-1, Reichert et al. 2011a). More recently (2007-2011), the greatest number of active nests has been on LTOHO (see Chapters 5 and 9 for more details on shifts in kite nesting distribution); these nests were associated with kites foraging on the exotic snail *Pomacea insularum*.

Note that for all researchers that have monitored snail kite nests, the number of active nests reported is most likely less than the number of active nests that actually existed (R. Bennetts Comment Matrix, Comment #11, Appendix B). The number of nests detected is a function of effort and other factors (which may vary) that are described in this report as affecting the 1969-1994 annual snail kite count (see Chapter 5, "Annual Count Data and Baseline Estimates of Survival and Recruitment").

Table 3-1. Number of active snail kite nests (containing at least 1 egg) by wetland for 1996-present. Data sources listed below table.

Location	1996 [1]	1997 [1]	1998 [1]	1999 [1]	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
WCA1	----	2 (1)	9 (14)	----	----	----	0	----	0	0	0	0	11	3	---	---
WCA2A	1 (0)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	---
WCA2B	3	19 (25)	102 (125)	0	0	0	11	17	18	0	2	0	0	0	---	1
WCA3A	73 (80)	168 (247)	178 (221)	66 (70)	112	0	60	82	48	12	58	3	0	11	15	23
WCA3B	0	0	2 (3)	3 (5)	26	0	3	2	6	0	17	1	0	0	9	2
ENP	5	0	0	0	12	0	----	----	0	0	22	5	0	8	3	2
LOKEE	31 (34)	3 (4)	6 (8)	0	0	0	0	5	8	23	10	0	0	0	14	39
Grassy Waters	0	5 (2)	3	0	3	0	----	3	0	14	1	0	0	0	8	4
BCWMA	16	22 (26)	9	12	6	1	1	10	22	9	16	0	2	2	14	2
LKISS	0	6	5	39	3	29	4	12	8	9	1	7	11	14	1	11
LTOHO	23	28 (38)	0 (2)	3	7	15	22	17	0	47	28	79	84	67	63	78
E LTOHO	----	----	----	----	----	4	4	1	1	1	1	1	11	13	12	60
Other	8	1	6	5	----	----	----	----	----	4	3	3	18	10	51	9
Total	160 [2] (169)	254 [2] (350)	320 [2] (396)	128 [2] (134)	169	49	105	149	111	119	159	99	137	128	190	235
Other-BCNP	8	1	5 (6)	5	---	---	---	---	---	0	---	0	0	1	0	---
Other-ISTOK	---	---	---	---	---	---	---	---	---	4	0	3	16	6	1	4

[1] Main numbers are from V. Dreitz (see citations below); those in parentheses are from Martin et al. (2002a) and/or USFWS (2007). All numbers were reported as active nests, but there were discrepancies between the various sources where two numbers are shown.

[2] For 1996-1999 Totals, we summed the individual #s shown; in the original sources, discrepancies existed. View these totals as approximations.

Data Sources: 1996-1999 data: Dreitz and Kitchens (1997 [for 1996]) and Dreitz et al. (2000).
2000 data: Martin et al. (2002a) and USFWS (2007) (V. Dreitz collected data). 2001-2006 data: Martin et al. (2002a, 2002b, 2003, 2005a, 2006b, & 2007b).
2007-2011 data: Cattau et al. (2007, 2008, and 2009), and Reichert et al. (2011a and 2011b), respectively.

Data for LKISS prior to ~ 2002 collected by Jim Rodgers, FFWCC. Data for LKISS for 1996-2000 & LTOHO for 1999 from USFWS (2007) and Martin et al. (2002a). Martin et al. noted no monitoring done at E LTOHO for these years before 2001. [FFWCC monitored there 1987-1991].

ROOSTING

Snail kites roost communally (Sykes 1985, Bennetts et al. 1994, Rumbold and Mihalik 1994), particularly during the nonbreeding season (Sykes 1982, Beissinger 1988). In Florida, the number of kites recorded using communal roosts has ranged from two to 372 birds at one time (Sykes 1985, Takekawa and Beissinger 1989). In a study of roost sites in WCA3A and on LKISS, Darby et al. (1996) found that 20% of 35 snail kites followed roosted alone.

Roosts are always located over water (Sykes et al. 1995). In Florida, the vast majority of roost sites are in stands of coastal-plain willow (91.6%), followed by punk-tree or melaleuca (5.6%), and pond cypress (2.8%; Sykes et al. 1995). Willow roosts were described as being 1.8-6.1 m in height and 0.02-5 ha in size; melaleuca and pond cypress roosts were 4-12 m in height and up to 0.02 ha in size (Sykes 1985). Darby et al. (1996) also observed kites roosting in herbaceous vegetation (cattail, bullrush, and sawgrass).

The importance of roosts to snail kite demography is not clear and has generally not been discussed in the literature. It is possible that roosting behavior and/or roost site availability influences survival, because roosts provide cover from an important predator, the great horned owl (*Bubo virginianus*). Owls prey on adults and juveniles (Bennetts et al. 1998b; also discussed below under "Mortality"). Bennetts and Kitchens (1999) suggested that a January to February decrease in adult and juvenile survival may have been partially due to the seasonal loss of willow leaves. Without the willow leaves, concentrations of roosting kites may have been more obvious to nocturnal predators (Bennetts and Kitchens 1999). Vulnerability to other predators while roosting has not been reported. To our knowledge, human disturbance (e.g., night-time airboat activity) at roosts has not been addressed.

CAUSES OF SNAIL KITE MORTALITY

Estimates of snail kite survival are a significant topic in this report and are addressed primarily in Chapter 5; here we focus on causes of mortality, rather than specific rates and what influences those rates. Causes of mortality of juvenile and/or adult kites include predation, exposure, emaciation, disease and parasites, and shooting (Sykes et al. 1995). Over a three-year study which used radio telemetry, Bennetts et al. (1998b) found 31 post-fledging juveniles and 16 adult snail kites dead or dying. Of the 31 juveniles, the probable causes of mortality were: predation (32.2%), starvation (6.5%), vehicle collision (3.2%), gun shot (3.2%), unknown-undisturbed (12.9%; carcasses found intact with no sign of predation), and unknown (41.9%; no evidence of cause of death, or birds were severely decomposed). Of the 16 adults, the probable causes of mortality were: predation (43.8%), vehicle collision (12.5%), disease (6.3%), unknown-undisturbed (18.8%), and unknown

(18.8%). The predator most frequently suspected in the deaths was the great horned owl; evidence included snail kites found decapitated on their nests, which is known to occur with great horned owl predation. Other kite carcasses had their feathers plucked or were found at a feeding/plucking perch with carcasses of other species. In addition to the great horned owl, the barred owl (*Strix varia*) is thought to be a predator of snail kites (Sykes et al. 1995). Of the two diagnosed cases of starvation, the birds were found alive but extremely weakened and emaciated (and did not recover; Bennetts et al. 1998b). Both birds were found in marine habitats where apple snails did not occur. The authors point out that their data were collected during non-drought years, and that more adults and/or juveniles may die of starvation during drought years. [However, during one "severe" drought period (during 1981-1982), at least seven of eight adult kites (88%; fate of one bird unknown) carrying radio transmitters survived the drought (Snyder et al. 1989b)].

Snail kite eggs are preyed upon by crows (*Corvus* spp.), boat-tailed grackles (*Quiscalus major*), rat snakes (*Elaphe obsoleta*), cottonmouths (*Agkistrodon piscivorus*), and raccoons (*Procyon lotor*; Chandler and Anderson 1974, Beissinger 1986, 1988, Sykes 1987b, Snyder et al. 1989a). Nestlings, for which predation is a significant cause of death, may be killed by rat snakes and cottonmouths, raccoons, Northern harriers (*Circus cyaneus*), great horned owls, and ants (*Crematogaster atkinsoni*) and dermestid beetle larvae (*Dermestes nidum*; Sykes and Chandler 1974, Snyder et al. 1984, Beissinger 1986, 1988, Sykes 1987c, Bennetts and Caton 1988, and Snyder et al. 1989a). Other causes of nestling mortality are exposure (e.g., during long periods of rain), disease (e.g., pneumonia), nest collapse, and accidents (e.g., nestlings falling out of nests; Sykes 1987c).

PARASITES AND DISEASES

The snail kite is a definitive host for some parasites (e.g., see Cole et al. 1995) and very likely subject to a variety of diseases, but documentation has been limited. Nestling kites have been reported as dying from acute pneumonia of unknown origin (Kerr 1977) at LOKEE. A dead fledgling snail kite at East LTOHO was found to be infected with *Aspergillus* sp. (a fungus), but the kite did not have aspergillosis (N.J. Thomas, R.A. Cole, D.J. Forrester, and M.G. Spalding unpublished data, as cited in Sykes et al. 1995). Snail kite fecal samples have revealed oocysts of intestinal coccidia (*Eimeria*; Sykes and Forrester 1983), but the significance of the finding was unknown (Sykes et al. 1995). Two dead snail kites (a fledgling and a subadult) collected in 1983 were infected with parasitic trematodes (*Bothrigastor variolaris*), which had not been reported previously from birds in the U.S. (Cole et al. 1995). In the fledgling kite, a large number of the parasites (270) caused air sacculitis and bronchitis, probably playing a role in the bird's death. Snail kites probably become infected with the parasite by eating snails which carry the metacercaria (Cole et al. 1995).

Bothrigastor variolaris was previously reported in snail kites in Brazil and Cuba (Sykes and Forrester 1983). Sharp (2008) completed a dissertation describing the occurrence of digenetic trematodes in native apple snails in ENP. Seven species of juvenile digeneans (cercariae) were isolated from Florida apple snails. Adult snails were found to be more susceptible to infection than juveniles, and multi-species infections were observed. No difference in probability of infection between sampling sites or hydrologic seasons was observed for apple snails. The degree to which these infections might influence snail kites is unknown.

A number of parasitic arthropods are known to infest snail kites in Florida; these include mites (*Ornithonyssus bursa* and unidentified mites), chewing and biting lice (*Colpocephalum turbinatum*, *Falcolipeurus guadriguttatus*, and *Craspedorrhynchus obscurus*), and mosquitoes (*Anopheles crucians*, *A. walkerii*; Malcomson 1960, Sykes 1983a, Sykes and Forrester 1983, Bennetts et al. 1988, and D.J. Forrester and M.G. Spalding unpublished data [as reported by Sykes et al. 1995]). Mosquitoes were found to feed on nestlings on the exposed skin at the base of the bill (Sykes 1983a). While lice are probably not particularly harmful, large numbers of mites or mosquitoes may harass nestlings or result in death (Sykes et al. 1995). Also, Snyder et al. (1984) discovered larval dermestid beetles (*Dermestes nidum*) feeding on the abdominal region of some nestling snail kites. In the worst cases, nestlings (1-4-wks old) had abdominal lesions up to 7 mm wide and as deep as the body cavity. Only two nests were rechecked to examine whether chicks recovered. At one of the nests, all chicks' wounds had completely healed; the chick at the second nest was missing, so its fate was unclear (but the authors believed that the weakened chick had probably died due to the larval beetle damage).

LIFE SPAN

In 1995, Sykes et al. summarized what was known about the snail kite's life span at the time. There had been reports of birds known to live at least 9 years (Sykes 1979), 11-13 years (Beissinger 1986), and 17 years (Bennetts and Kitchens 1993). Based on their work, Bennetts and Kitchens (1997a) reported that snail kites may live and breed up to at least 18 years of age; 13-15-year-old kites often nested. Some of these older adults that were observed by Bennetts and Kitchens (1997a) have since been observed during more recent kite monitoring (Reichert et al. 2010); some of these birds are now 25 years old (see details of age dependent survival in Chapter 5).

RANGE OF THE SNAIL KITE

The snail kite's original range in Florida was much larger than it is today (Sykes et al. 1995). Sykes (1984) notes that before around 1900, snail kites were probably found, at least when conditions

were favorable, in most freshwater marshes that contained apple snails from about 29°15' north latitude (i.e., vicinity of Ocala), south to the mangrove forests at the tip of the state. The range in the early 1900s (see Figure 3-5) included the eastern Florida panhandle, including the Wakulla River (Wakulla Co.) and lower Wacissa River (Jefferson Co.; Howell 1932, Sykes 1984, Sykes et al. 1995). Kites were reported in nearly half of the state's counties from 1844 to 1949, in about 15% of the counties from 1950 to 1967, and in about 24% of the counties from 1968 to 1980 (Sykes 1984). From 1968-1980 the range was reduced to an estimated 9% of the original range. As of the mid 1990s, the range was described as from the East Orlando wetlands (latitude 28°35'N), south to the C-111 basin (latitude 25°16'N) (Sykes et al. 1995). Areas in which the kite was no longer known to occur included Gulf Coast counties, most lakes in the central peninsula, former marshes along the Kissimmee River, the Everglades Agricultural Area to the south and east of LOKEE, WCA3A north of Alligator Alley, and south ENP (Sykes et al. 1995).

Critical Habitat and Other Important Wetlands Used

Critical habitat was designated for the snail kite in 1977 (Federal Register Vol. 42, No. 155 [Pp. 40685-40688]). Designated critical habitat includes: 1) St. Johns Reservoir, 2) Cloud Lake Reservoir, 3) Strazzulla Reservoir, 4) western portions of LOKEE, 5) LNWR, 6) WCA2A, 7) WCA2B, 8) WCA3A south of Highway 84 (which parallels Interstate 75), and 9) a portion of ENP (see Figure 3-6). There have been no revisions of critical habitat since the time it was first designated. Bennetts and Kitchens (1997a) reported that about 40% of the locations where radio-transmittered snail kites were observed were outside of designated critical habitat, and 67% of transmittered adults used habitats other than critical habitat at some point during the study. In the last several years, WCA2B and WCA3A have been largely abandoned by kites, likely due to low snail densities (Darby et al. 2009).

Other areas not federally-designated as critical habitat, but that have been or are used frequently by snail kites include (**but are not limited to**): 1) lakes in the Kissimmee Chain-of-Lakes (e.g., LKISS, LTOHO, and East LTOHO; 2) the Blue Cypress Marsh Conservation Area/Blue Cypress Water Management Area (BCMCA/BCWMA, part of the Upper St. Johns region; 3) wetlands associated with the Loxahatchee Slough (e.g., Corbett Wildlife Management Area, Pal-Mar Water Control District, and West Palm Beach Water Catchment Area [now known as Grassy Waters Preserve {GWP}]); and 4) BCNP (Bennetts and Kitchens 1997a). Areas such as LISTOK, WCA3B,

Figure 3-5. The range of the snail kite prior to 1910 (gray shading), isolated confirmed locations from 1910 to 1967 (black triangles), and possible, but unconfirmed, locations (*). Major lakes included in the range are shown for geographic reference (other lakes part of the Kissimmee Chain-of-Lakes and St. John's River were also used by kites). LGEORGE=Lake George (part of the St. John's River Basin, LTOHO=Lake Tohopekaliga, LKISS=Lake Kissimmee, LPANA=Lake Panasoffkee, LISTOK=Lake Istokpoga, LOKEE=Lake Okeechobee, LOX_SL= Loxahatchee Slough. Adapted from Sykes (1984), and used by kind permission from the Bulletin of the Florida Museum of Natural History: The range of the snail kite and its history in Florida, Bull. Florida State Mus., Biol. Sci., Vol. 29, 1984, Pages 221-264, P.W. Sykes, Jr., Figure 5.

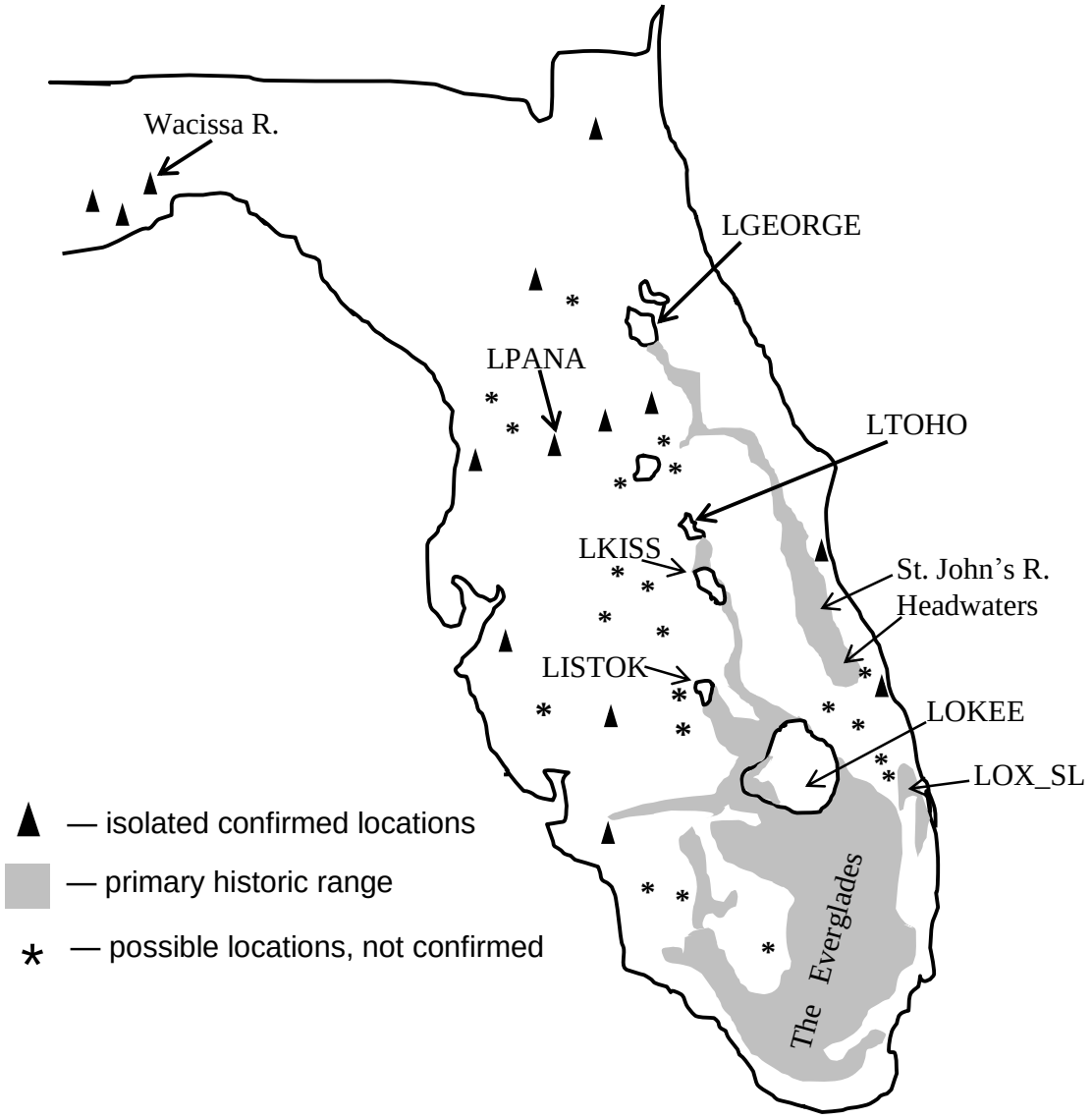
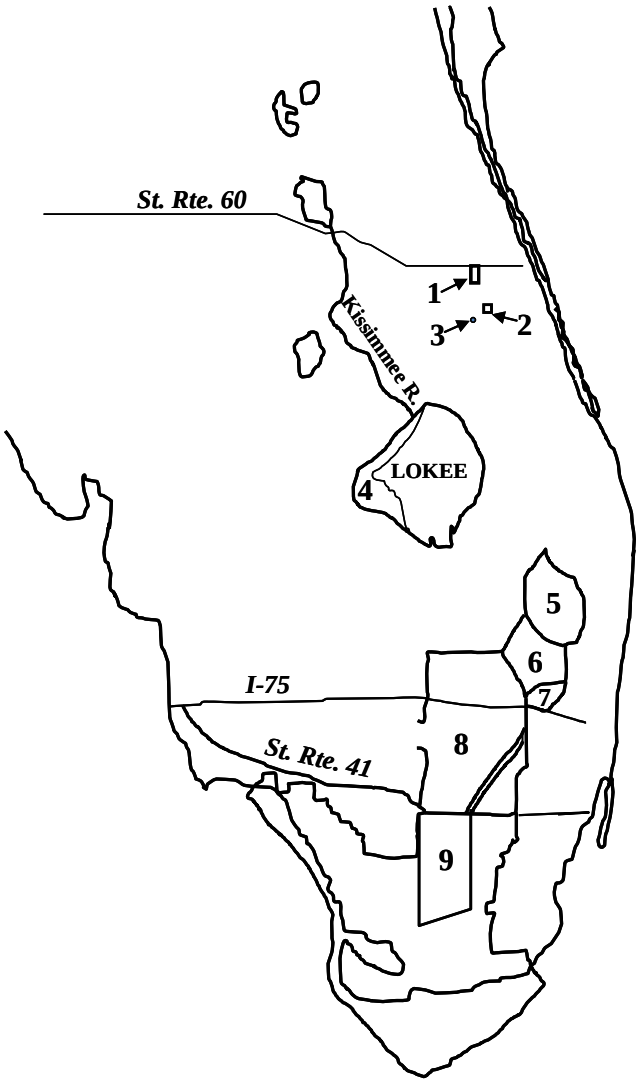


Figure 3-6. The current federally-designated critical habitat for the snail kite in Florida as described in Federal Register Vol. 42, No. 155, August 11, 1977. Wetland units designated are: 1) St. Johns Reservoir, 2) Cloud Lake Reservoir, 3) Strazulla Reservoir, 4) western marshes of Lake Okeechobee (LOKEE), 5) Water Conservation Area (WCA) 1, 6) WCA2A, 7) WCA2B, 8)WCA3A south of I-75, and 9) portions of Everglades National Park.



and Holey Land Wildlife Management Area have also been used. Additionally, wetlands peripheral to the main areas (e.g., ephemeral wetlands, agricultural retention ponds, and ditches scattered throughout the kite's range) may provide important habitat to snail kites during drought periods or on a seasonal basis (e.g., Beissinger and Takekawa 1983, Valentine-Darby et al. 1998, Meyer and Kent 2011).

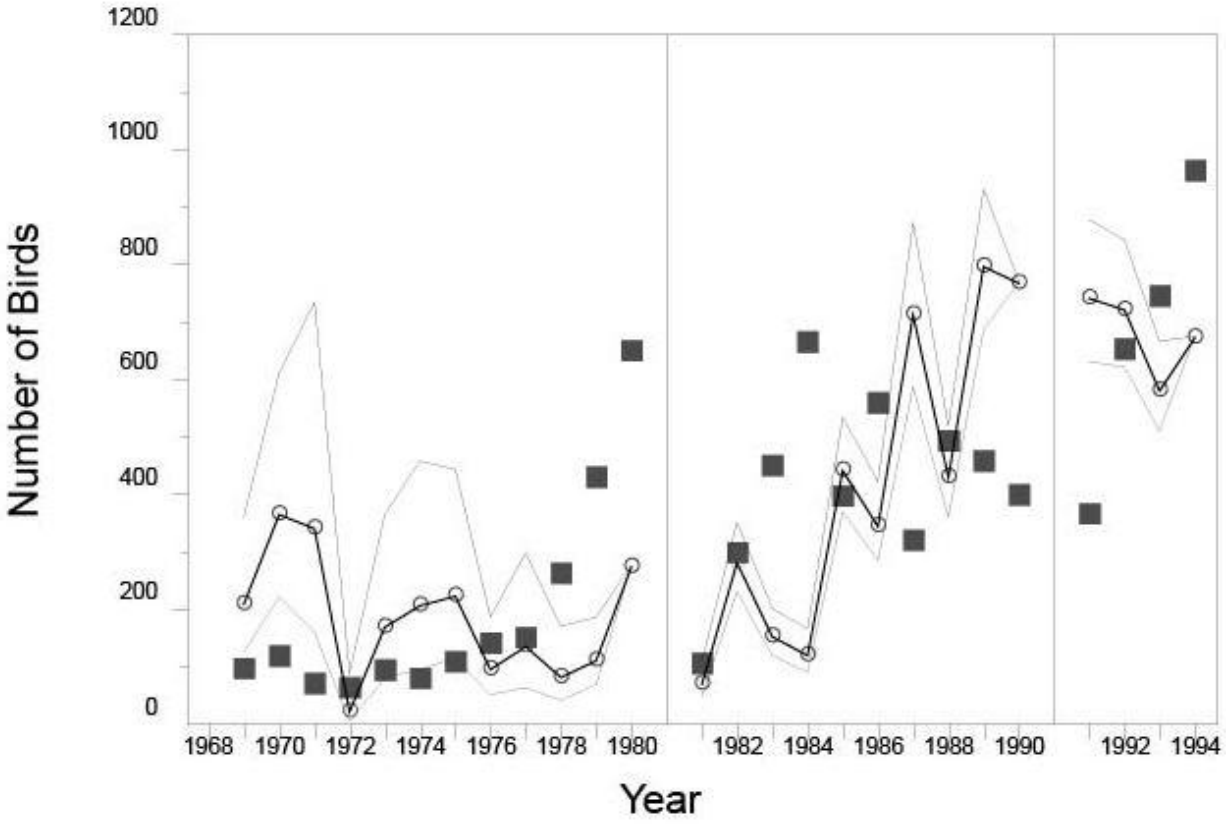
OVERVIEW OF SNAIL KITE POPULATION TRENDS

The snail kite was described as locally abundant in the areas where it was reported in the late 1800s and early 1900s (Sykes et al. 1995). Reports in the 1930s through the mid 1960s indicated a substantial decline in the range and numbers of kites (Howell 1932, Bent 1937, Sprunt 1945, 1954, Wachenfeld 1956, Stieglitz 1965). In the early 1940s, Sprunt (1945) estimated that there were 50-100 snail kites remaining in Florida, but dropped this estimate to 50-75 kites during the next decade (Sprunt 1954). Later estimates were that 20 or fewer kites remained (Wachenfeld 1956, Stieglitz 1965). Although these estimates were most probably underestimates due to the limited access to snail kite habitats, they all indicated that snail kite numbers were low (Sykes et al. 1995).

As described in Chapter 2, an annual count (a "census") of snail kites was conducted from 1969 to 1994. [Since that time, kite population estimates have been made from mark-resighting studies that rely on breeding season surveys and banding nestlings (also see history of kite monitoring in Chapter 2)]. Counts were conducted from the ground, mainly from airboats, in the winter (primarily November-December) using transects and evening roost counts. The counts were quasi-systematic, and although this information is important from an historic perspective, several researchers pointed out that care must be taken in interpreting the information (e.g., Rodgers et al. 1988, Bennetts et al. 1993, Sykes et al. 1995, Bennetts and Kitchens 1997a, Bennetts et al. 1999a; see Chapter 5, "Annual Count Data and Baseline Estimates of Survival and Recruitment" for more details). The counts from 1969 to 1994 ranged from 65 kites in 1972 (Sykes 1983b) to 996 in 1994 (Bennetts et al. 1994, Sykes et al. 1995; Figure 3-7, solid squares).

A realization that the annual count had inherent limitations as a census (see Chapter 5) led Bennetts et al. (1997a) to initiate a systematic banding protocol that would become the foundation for a mark-resighting survey of kites; these methods allowed survival and population estimates to be made (Bennetts et al. 1997a). After Bennetts et al., these surveys were conducted by Dreitz et al., Martin et al., Cattau et al., etc. (see history of kite monitoring, Chapter 2). The snail kite population size was first estimated for the year 1997 using mark-resighting data (Dreitz 2000, Dreitz et al. 2002a). This work was the first to estimate the population size while accounting for detection probabilities and spatial variation, and used a recently-developed estimator of superpopulation size

Figure 3-7. Estimates (±SE) of snail kite population change from 1969-1994 (open circles connected by lines), adjusted for effort (observer days), observer (Sykes, Rogers, or Bennetts), site, and water level (i.e., accessibility depending on water levels). Solid squares denote unadjusted counts from the annual fall survey. Figure from Bennetts et al. (1999a); provided by R. Bennetts and used by permission from the American Ornithologists' Union: The Auk, Factors influencing counts in an annual survey of snail kites in Florida, Vol. 116, 1999, Pages 316-323, R.E. Bennetts, W.A. Link, J.R. Sauer, and P.W. Sykes, Jr., Figure 3.



(see Chapter 5 for additional details). A peak in the population occurred in 1999, with an estimated 3,577 (Dreitz et al. 2002a) or 3,400 (Cattau et al. 2009) snail kites. The population dropped by about 50% from 1999 to 2002 (Cattau et al. 2009). The population was more stable between 2002 and 2006, at about 1,500-1,600 kites. It dropped again, however, in 2007 and 2008 to an estimated 1,204 birds (SE=77) and 685 birds (SE=38), respectively. The estimates for 2009-2011 were similarly low, at 662 birds (SE=34; Cattau et al. 2009), 826 birds (SE=49; Reichert et al. 2011a), and 925 birds (Reichert et al. 2011b), respectively.

OVERVIEW OF DECLINE IN SNAIL KITE DISTRIBUTION AND ABUNDANCE

As described above, snail kites began being described as in decline or rare around the 1930s. Widespread drainage throughout Florida was named as the primary cause (Howell 1932, Sprunt 1945, Sykes 1983b, Bennetts et al. 1994). About 50% of the wetland habitat available to kites in the southern half of the Florida peninsula has been lost since the early 1900s (Sykes 1983b). This habitat loss has been due to the drainage of large portions of the Everglades, impoundment and compartmentalization of other portions of the system, hydrologic modification and manipulation, and an increase in nutrients entering the system (Stieglitz and Thompson 1967, Bennetts et al. 1994, Sykes et al. 1995, USFWS 1999, Sklar et al. 2002, McVoy et al. 2011). For example, the straightening of the Kissimmee River altered floodplain wetlands. Similar habitat loss has occurred in other marsh and lake habitats in the peninsula, such as the conversion and manipulation of marshes in the Upper St. Johns River Basin, and the drainage of wetlands throughout the peninsula. While the Kissimmee Chain-of-Lakes, LOKEE, and the Everglades were once a single hydrologic unit, they now are subdivided (Kitchens et al. 2002), creating many issues, including habitat fragmentation for the kite (Martin et al. 2006a). Nutrient enrichment stimulates the growth of some plants, such as cattail (*Typha* spp.), which may result in cattail expansion and a reduction in available foraging habitat for snail kites (e.g, Sykes 1987b). The expansion of cattail has been reported in the Everglades system and other parts of the peninsula (e.g., the Everglades Agricultural Area, WCA1, edges of LNWR, WCA2A, BCWMA/CA; see Newman et al. 1998, Sklar et al. 2002, Surratt et al. 2012). Nutrient enrichment may also negatively impact periphyton communities thought to be an important component of apple snail habitats (see Chapter 4). Increased phosphorus levels can lead to the break-up and disappearance of calcareous floating mats (McCormick et al. 1998).

Drainage of the Everglades (including in the Kissimmee Chain-of-Lakes and at LOKEE) began in 1880, and four major canals (Miami, North New River, Hillsboro, and West Palm Beach) were constructed between 1910 and 1920 (Sklar et al. 2002). These activities reduced water tables (in some places up to 2.7 m [9 ft]), changed the direction of surface water flows, altered vegetation,

affected normal fire patterns, and caused significant soil subsidence. Other major alterations also occurred, such as the creation of the Tamiami Trail and construction of the 10-m-tall dike at LOKEE (Ewel 1990). [For a detailed description of the history of drainage in the Everglades, see Sklar et al. (2002) and McVoy et al. (2011)]. In the late 1940s, the Central and South Florida (C&SF) Project for Flood Control and Other Purposes was undertaken to provide flood control, water supply for municipal, industrial, and agricultural uses, prevention of saltwater intrusion, water supply for ENP, and protection of fish and wildlife resources. The project developed a system of levees, borrow canals, and water control structures to impound undeveloped lands in the Everglades (to more effectively manage the developed areas and to protect soils and create wildlife habitat in the undeveloped areas; Sklar et al. 2002). The system compartmentalized the landscape and continued to alter water tables and surface flows; it led to the ponding of water in the southern portions of the WCAs, more frequent and intense fires in the northern portions of the WCAs, and disrupted natural flows. Lowered wetland elevations, resulting from drainage and its associated effects, have also rendered the WCAs more susceptible to excessive ponding. Presently, the WCAs are managed in accordance with a set of regulation schedules that determine when water levels should be maintained and when flood control releases should be made (Sklar et al. 2002).

The impacts of this alteration and current land uses (e.g., intensively managed agriculture and urban development) include: loss of water storage, overland flow, and spatial extent; fragmentation of the Everglades; changes in timing, distribution, and quantity of water; altered fire regimes; the invasion of non-native plant species; and freshwater discharge to estuaries (Sklar et al. 2002). Such changes have led to less available habitat for the snail kite and apple snail, as well as degradation of the remaining habitat. Unfortunately, the degree to which these landscape changes impacted kite abundance and recruitment remains unknown because no systematic sampling had occurred prior to 1969. At the current time, we can only discuss the response of snail kites to hydrology and habitat structure in the remaining wetlands. Quantitative assessment of the impact of hydrologic and habitat changes in the remaining wetlands used by kites is presented in detail in Chapter 5.

CHAPTER 4: OVERVIEW OF THE LIFE HISTORY, ECOLOGY, AND DISTRIBUTION OF THE FLORIDA APPLE SNAIL

Note that throughout this report, we may refer to Florida apple snails as "apple snails," or, in some cases, "snails." If the distinction between Florida apple snails and other species of snails is important to the discussion, we will make it clear to which snails we are referring.

INTRODUCTION

The Florida apple snail (*Pomacea paludosa*, Say), the largest native freshwater snail in North America (Pennak 1953), is a critical component of Florida aquatic food webs. It is one of about 100 apple snail species worldwide recognized as having importance ecologically (see reviews in Cowie 2002 and Turner and Mikkelsen 2004). *Pomacea paludosa* serves as important prey for a number of avian and aquatic predators. In the 1990s, apple snail research was identified as a high priority in wetland restoration efforts in all South Florida wetlands, including the Everglades (USFWS 1999), the Kissimmee River (Dahm et al. 1995), and the Upper St. Johns River Basin (Turner 1994, Miller et al. 1998). Up through 1992, 25 years after listing the snail kite as endangered, there were only three peer-reviewed publications (Perry 1973, Hurdle 1974, Kushlan 1975) reporting direct field observations of Florida apple snails (e.g., survival, distribution, abundance) in the context of their being the snail kite's primary prey. There was recognition that while the information base on the snail kite was building (at least 35 publications by 1992), little was known about the ecology of its primary food source.

TAXONOMY AND PHYSICAL DESCRIPTION

The Florida apple snail belongs to the molluscan family Ampullariidae (Cowie 2002). This family comprises several genera that occupy tropical and subtropical freshwater aquatic systems (Prashad 1925, Pain 1960, Aldridge 1983, Cowie 2002). The genus P*omacea* is a New World genus (North, South and Central American) in which the members have a corneous (horny-textured) operculum (see Figure 4-1); this is in contrast to members of the genus *Pila* (Old World [African, Asian]), which have a calcified (bone-like) operculum (Cowie 2002).

Some species in the family Ampullariidae are referred to as "apple snails" because of their overall large, globose form (Keawjam 1986). The main characteristic that distinguishes ampullarid snails is the presence of both a ctenidium (analogous to a gill) and a lung (a pulmonary sac created by the mantle) for respiration (Prashad 1925, Andrews 1965, Aldridge 1983). The presence of the lung promotes snail survival in habitats that experience seasonal fluctuations in water levels, including dry

Figure 4-1. Florida apple snail shell (left) with detached operculum (right). Pictured snail shell was 47 mm in length and 43 mm wide (see Figure 4-3 for measurements). In a live snail, the operculum is attached to the snail foot and closes the aperture to seal the soft body tissues inside the shell (e.g., during aestivation). Photo by Phil Darby.

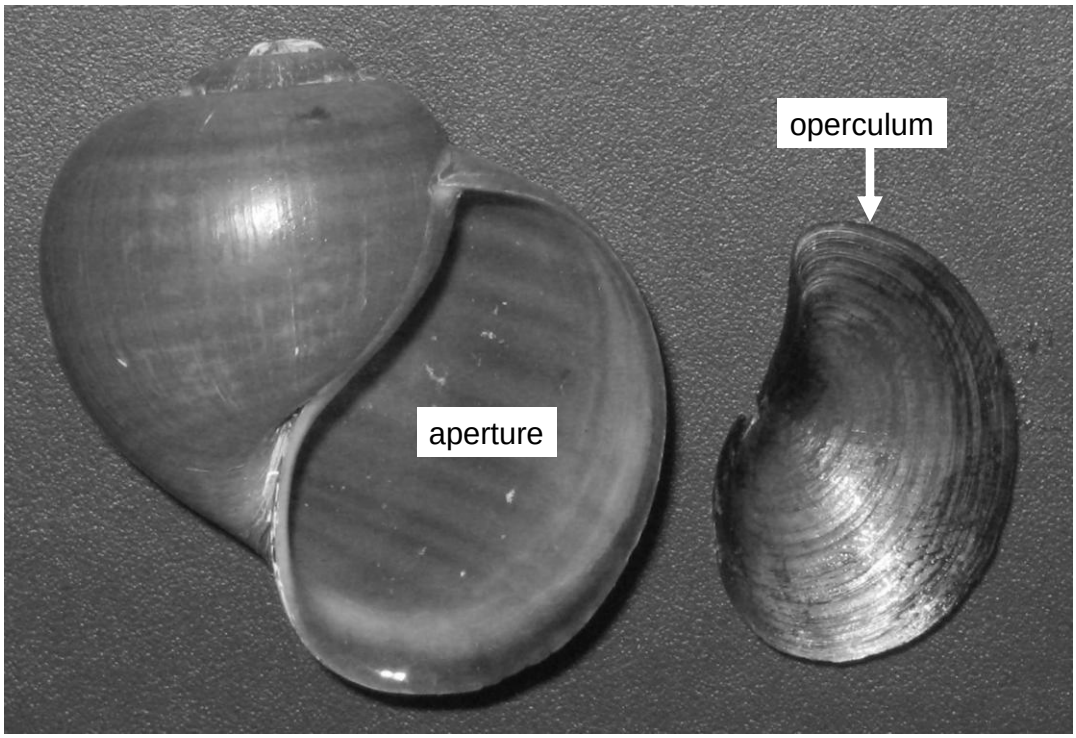


Photo by Phil Darby

downs, which are common in their range (Prashad 1925, Pain 1950, Visser 1965, Burky et al. 1972, Kushlan 1975, Haniffa 1978a and 1978b, Keawjam 1986, Cowie 2002). The presence of both a lung and a ctenidium enables the snail to tolerate low dissolved oxygen concentrations typical of warm, shallow, tropical and subtropical wetlands (McClary 1964). The rate of surface inspiration using the lung increases with increases in temperature and decreases in dissolved oxygen (McClary 1964; see Figure 4-2). The pseudo-lung also allows the Florida apple snail and some other ampullarid snails to lay their eggs out of the water— a strategy thought to avoid hypoxic conditions for developing eggs and, possibly, aquatic predation (Aldridge 1983). Snails are known to crawl underwater along the surface of the substrate and vertically or horizontally along plant stems. Snails can also drop from the surface of the water by moving air out of their air sac (Burky and Burky 1977). By controlling their buoyancy, they can also float at the surface of the water (P. Darby, pers. obs.).

Reference to snail sizes and shell measurements have been confused by different investigators referring to different shell measurements with different names. For example, what Sykes (1987b) referred to as width, Thompson (1984) labeled as height, and Youens and Burks (2008) labeled as length. Youens and Burks (2008) suggested standardized names for shell metrics. However, they did not define a total shell width, which Darby et al. have used frequently in their field measurements of snails (e.g., sizes reported in Darby et al. 2002, Darby et al. 2008). Because apple snails are globose, we can also refer to an approximate diameter. For the purposes of this document, we report the metrics shown in Figure 4-3. If a paper refers to a different measurement, we will point out the difference.

All *Pomacea* snails are dioecious (i.e., they have separate sexes; Cowie 2002); hermaphroditism and sex reversal have never been documented. Males can be identified by the presence of a pallial penis and penis sheath, and females can be identified by their large, orange albumen gland (Hanning 1979). Gender can also be distinguished, although less definitively (P. Darby, pers. comm.), from shell morphology (Hanning 1979, Valentine-Darby et al. 2011). Males have less swollen body whorls, wider apertures, and flaring aperture margins (Hanning 1979). Shells of the females are more globose and have narrower apertures. Differences in shell morphology of native apple snails are more obvious with adult snails (Hanning 1979, Darby et al., unpublished). Hanning also commented that sexual dimorphism was more pronounced in northern populations (north of LOKEE), but he provided no quantitative evidence to support that assertion. Typical adult-sized Florida apple snails range from 30-45 mm shell length (Hanning 1979, Darby et al. 2003); the largest-sized snails (>50 mm) are usually females.

Figure 4-2. Florida apple snail taking in air via its extended siphon. Photo courtesy of Rob Bennetts.

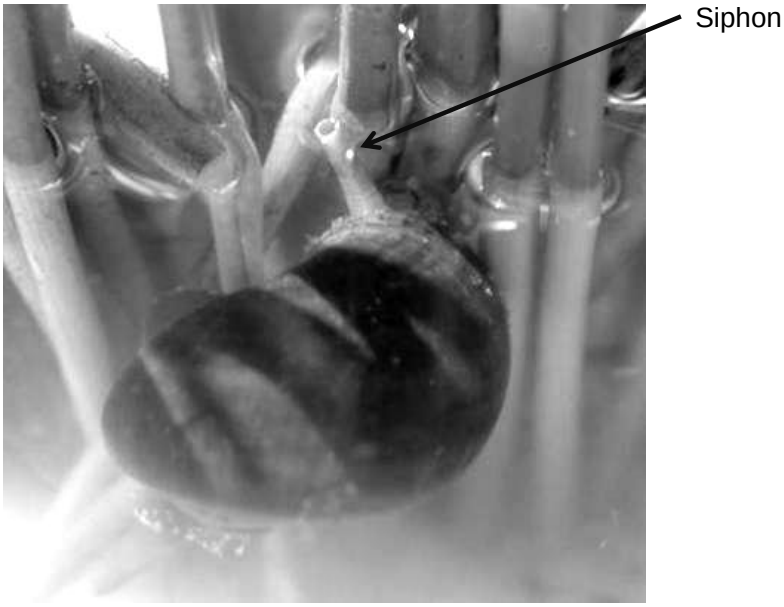


Photo by Rob Bennetts

Figure 4-3. Apple snail shell measurements referred to in this report. AL=aperture length, AW=aperture width. Snail shell shown is a native Florida apple snail (34 mm total length x 31 mm total width). Image by Phil Darby.

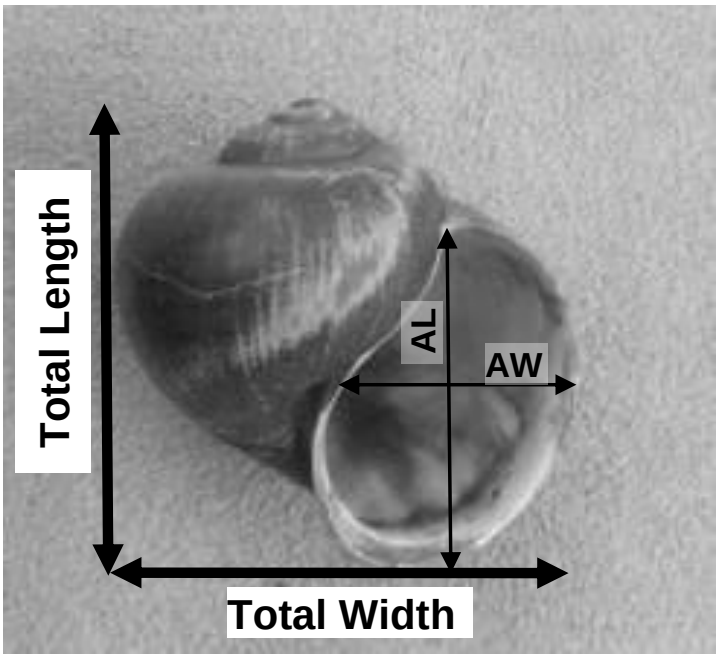


Image by Phil Darby

The average shell length (n=871) of native apple snails collected at LOKEE was 39.1 mm (Hanning 1979). The largest female and male recorded on LOKEE were 55.7 mm and 53.5 mm, respectively. Females were more abundant than males in three months (February, July, and November) out of the period (differences from a 1:1 ratio were statistically significant), but ratios were not significantly different from a 1:1 ratio in all other months (Hanning 1979). Hanning dissected snails and found sexually mature adults with minimum shell size of approximately 35 mm. Based on observing egg-laying females and mating males collected in the field, Darby et al. (2008) reported a size somewhat smaller (25-30 mm lengths) for sexually mature native apple snails in the Upper St. Johns Marsh. Valentine-Darby et al. (2011) reported average shell lengths for female and male snails in BCWMA (=SJM) of 38.6 ± 4.1 (SD) mm and 37.4 ± 3.1 mm, respectively.

RANGE, DISTRIBUTION, AND GENERAL HABITAT NEEDS

The Florida apple snail's range in the U.S. extends from southern Georgia (in isolated springs) and Alabama (introduced in an artificially-heated reservoir) in the north, to the Everglades in the south (Haper 1936, Thompson 1984). *Pomacea paludosa* also occurs in Cuba (Thompson 1984). The snail is distributed widely throughout the Florida peninsula, but only sporadically in the panhandle west of the Suwannee River to the Choctawhatchee River (Thompson 1984). Their absence in the far western panhandle likely reflects lower-calcium waters associated with the surficial sand-based aquifer (Glass and Darby 2009). Snails can be found in a wide range of hydrologic conditions, from relatively short hydroperiod marshes in the Everglades (see O'Hare et al. 2010) to permanently flooded river and wetland habitats (see below). The distribution and abundance of the apple snail is probably determined by a variety of factors, only some of which have been studied. These factors include temperature (as affected by latitude; e.g., Thompson 1984, Stevens et al. 2002); habitat and/or vegetation type and density (e.g., Bryan 1990, Karunaratne et al. 2006, Darby 2006); hydrology, including hydroperiod, the frequency, duration, and timing of dry downs, and water depths (Kushlan 1975, Darby et al. 2005, Darby et al. 2008, Darby et al. 2009); predation (Darby et al. 2009); and water chemistry (e.g., Corrao et al. 2006, Glass and Darby 2009). Hurdle (1974) suggested that limiting factors for apple snails include alkalinity, which is an indication of the amount of calcium carbonate present, submerged plants (that are needed for food and cover), and possibly, dissolved oxygen. Although it has not been studied for apple snails, fire undoubtedly affects the distribution and/or abundance of snails through effects on their habitat. Fire is a fundamental driving force of plant community development in the Everglades (DeAngelis 1994). There may also be direct effects to snails, such as mortality of snails exposed to substrate fires and eggs lost on burned emergent vegetation (see Chapter 11 for a research recommendation).

As invertebrates, snails would be expected to be affected by temperature, and effects on Florida apple snail movements, behavior, and oxygen consumption have been reported (McClary 1964, Freiburg and Hazelwood 1977, Hanning 1979, Stevens et al. 2002). Freiburg and Hazelwood (1977) reported that Florida apple snails tolerated water and air temperatures in the range of 10-35 ºC. They reported temperatures of 40 ºC to be lethal; they did not report a lethal cold temperature, but stated that the species could survive at 5 ºC. Apple snails respond to cold temperatures by becoming less active. Surface inspiration decreases with decreases in temperature (McClary 1964, Freiburg and Hazelwood 1977), and snails may burrow into the substrate and become inactive (Hanning 1979, Stevens et al. 2002). In the laboratory, Stevens et al. (2002) monitored apple snail activity in water temperatures that ranged from 2-24 ºC. All snails (n=86) became inactive once temperatures dropped below 13 ºC. When temperatures dropped below 10 ºC, the majority of snails (92%) buried themselves in the substrate (partially or entirely). Two of the three snails that remained entirely above the substrate surface died somewhere in the 2-9.5 ºC water temperature range. In McClary's (1964) study, apple snails spent more time at the water's surface and inspired at a higher rate during warmer temperatures; for example, there was a 2.7-fold increase in the number of surface inspirations as temperatures rose from 12 to 26 ºC. [Importantly, there is some question about whether McClary (1964) and Freiburg and Hazelwood (1977) were working with *P. paludosa* or different *Pomacea* species (see Turner and Mikkelsen 2004)].

Calcium and pH are known limiting factors for freshwater gastropods (e.g., McKillop and Harrison 1972, Lodge et al. 1987, Watson and Ormerod 2004). Glass and Darby (2009) found that Florida apple snails growing in water with low dissolved calcium concentrations and relatively low pH grew slowly and had thin shells. They concluded that systems with dissolved calcium concentrations below about 10 mg/l and pH < 6.5 would support fewer apple snails than those with dissolved calcium concentrations above about 20-30 mg/l and with higher pH. [To provide a reference for these numbers, interior WCA1 water had average Ca^{2+} concentrations (±SD) of 5.7 ± 2.0 mg/l and average pH of 6.1 ± 0.47, and southwestern WCA3A water had Ca^{2+} concentrations of 78 ± 9.4 mg/l and average pH of 7.6 ± 0.31 (from DBHYDRO database [http://www.sfwmd.gov/org/ema/dbhydro, Glass and Darby 2009)]. Calcium carbonate is the essential material for shell construction in snails (Pennak 1953) and egg formation in *Pomacea* snails (Turner and McCabe 1990), and this is why hard water has greater snail diversity and more individuals (compared to soft water; Pennak 1953). Further, Gleason et al. (1975) found that apple snail egg cluster counts were positively correlated with specific conductivity, calcium concentration, and pH in wetlands of south Florida. Hurdle (1974) observed a similar association along a gradient of water chemistry conditions in a spring-fed creek in central Florida. Relatively low calcium sites (e.g., WCA1) can still provide

apple snails for foraging snail kites (see Darby et al. 2006), but the potential for these wetlands to support high apple snail densities, based on Glass and Darby (2009) and research on *Pomacea* snails elsewhere (Gutierrez et al. 1997, Martin et al. 2001), may be limited.

Apple snails live in both lentic and lotic systems, such as springs, lakes, and marshes. Snails can be found in a wide variety of habitat types within these systems, including those dominated by sedges, grasses, *Hydrilla* (both rooted and floating), cattail, sawgrass, broad-leaved emergents such as pickerelweed (*Pontederia cordata*), and in man-made aquatic systems like canals. Habitats used by the Florida apple snail must provide a food source (described below) and structure; however, because they frequently move, snails at any particular time may be found in habitat patches lacking these components. It is critical to consider the scale at which Florida apple snails traverse the wetland landscape (see Darby et al. 2002) in order to understand their distribution in relation to habitat structure. Structure (emergent plants) is required for egg-laying and climbing to the water's surface to respire (Turner 1996). Due to their need for emergent plants, apple snails are found on lakes primarily in the littoral zone (Darby 2006). In a spring system, where trees often provide emergent structure for egg-laying, snails were more prevalent in beds of *Vallisneria* (tape grass) compared to areas containing *Eichhornia* (water hyacinth) or *Pistia* (water lettuce) mats (Bryan 1990). Note that tape grass, as observed in some Florida springs and lakes, often reaches the water surface (Darby, pers. obs.), presumably allowing snails to breathe air even in the absence of emergent vegetation. In marshes in the Everglades (WCA1 and WCA3A), wet prairie habitats (dominated by emergent grasses and sedges) were found to support greater densities of apple snails than *Nymphaea*-dominated slough habitats (*N. odorata* [white water-lily]; Karunaratne et al. 2006). These authors also found that snail densities in wet prairies varied depending on the dominant emergent plant species and their densities. In a central Florida lake, no snails were found in areas with unconsolidated organic substrate, no SAV, and dominance by yellow cow-lily (*Nuphar luteum;* Darby et al. 2004). However, several years after a drawdown that consolidated the substrates, Darby (2007) reported adult-sized snail densities ≈ 0.8 snails/m^2 in this same site; SAV was established and snail eggs were observed on the emergent structures of yellow cow-lily (stems and leaves as well as the inflorescences). This raises another important point, that any reported snail abundance or density may reflect a population in transition as it increases in response to improving habitat conditions or as it decreases in response to habitat degradation.

Athough snail kites are not known to forage in sawgrass or cattail habitats, unless, perhaps, the vegetation is sparse or in clumps, some data have been collected on Florida apple snail densities in stands dominated by these plant types. Two studies reported apple snail densities in sawgrass or cattail— Darby et al. (1999) and Valentine-Darby et al. (2008). Both of these studies focused on

development of the apple snail sampling methods; sites were sampled based on signs of snail presence (i.e., sites were not randomly selected). Darby et al. (1999) reported snail densities between 0.1 and 0.2 snails/m^2 in three sawgrass sites in WCA3A. Valentine-Darby et al. (2008), using a mark-recapture method, reported similar estimates for two sawgrass sites in WCA3A (i.e., 0.12 snails/m^2 for both sites). The two cattail sites (also in WCA3A) had reported snail densities of 0.09 and 0.32 snails/m^2. Although these were relatively low snail densities (in terms of providing a forage base for snail predators), the critical structure that these habitats provide for snail oviposition, especially along the sawgrass ecotones, can not be over stated.

Although Florida apple snails may be found in a variety of water bodies and wetland types, important points to keep in mind for the subject of snail distribution in this report are: 1) are the snails present available to foraging snail kites (i.e., can kites see and access the snails that exist), and 2) are the snails at densities great enough to support the energetic requirements of foraging and nesting snail kites?

DIET

Apple snail species of the Ampullaridae family have been described as consumers of macrophytes, microscopic matter, and/or animal matter (Estebenet 1995). The Florida apple snail's preferred food source remains unclear, although consumption of several types of plant material have been reported. In the laboratory, growth and survival of Florida apple snails were highest when they were fed a *Utricularia* sp./periphyton complex or an *Eleocharis* sp./periphyton complex, compared to metaphyton (loosely attached benthic algae; Sharfstein and Steinman 2001). In another study, juvenile Florida apple snails showed higher growth rates when fed periphyton, compared to snails provided sawgrass detritus (Shuford et al. 2005). Rich (1990) and Browder et al. (1994) reported that Florida apple snails depend on periphyton for food. Rich's (1990) study found that periphyton was a major food component, but that vascular plant material may be as important. Florida apple snails maintained in aquaria are also known to consume *Hydrilla* and *Utricularia* (P. Darby, UWF, pers. comm.). In the field, Florida apple snails reportedly fed readily on two species available in managed impoundments at Lake Woodruff— muskgrass (*Chara* sp.) and spiny naiad (*Najas marina*; Hurdle 1974). Studies of the non-native apple snail *Pomacea canaliculata* (including size ranges that overlap with the Florida apple snail), indicate that this species is a generalist (see Cowie 2002); anecdotal evidence of the wide range of plant community and periphyton assemblages that support robust snail populations indicates the same is probably true for the Florida apple snail (P. Darby, UWF, pers. obs.).

Florida apple snails feed primarily by rasping at the substrate with their radulae (Andrews 1965, as cited in Cowie 2002), but they may also feed by collecting food from the surface film in a process called ciliary feeding (McClary 1964). During ciliary feeding, the snail's foot forms a funnel, and food is drawn in by the movement of cilia on the foot; the food moves down the tube and collects at its base. The importance of grazing versus macrophyte consumption versus ciliary feeding, and any ontogenetic shifts in diet (i.e., during the course of a snail's development) have yet to be documented.

APPLE SNAIL MOVEMENTS

Apple snail movements may be affected by various environmental and other (e.g., biological) factors. For example, water temperature is known to influence snail activity (Stevens et al. 2002). The effects of water depth on apple snail movements have been studied and are addressed in Chapter 6, along with other aspects of snail ecology that may be affected by management. Snail movements in the spring season may be influenced by reproductive activity (Valentine-Darby et al. 2011). In a study in BCWMA using radio transmitters, these researchers found that there were differences in the distances and patterns snails traveled over time and according to gender. Males traveled the greatest distances, and they showed a greater tendency to maintain a consistent bearing than did females. Male movement distances were at their greatest during the typical peak of the breeding season. Female snail movements did not vary over time. Another component of their study, using wire funnel traps, suggested that male snails tracked females into traps (with all snails crawling into traps on their own accord), especially during the April-May peak in the breeding season. Male and female apple snails in the study moved an average of 14.8 ± 10.3 (SD) m per week. The greatest snail movement recorded over the course of a week was 83 m (Darby et al. 2002). Note that these weekly snail movements represent the minimum distance actually traveled; because the distance traveled was the distance between a snail's location in one week and the next, the measurement method would not have captured all of the movements made by the snail over the course of the week.

EGG-LAYING

The Florida apple snail lays its eggs on emergent vegetation (Turner 1996), or other emergent structures if available (e.g., boat docks). Females emerge at night or in the early morning to lay eggs (the process is called oviposition). Each clutch or cluster of eggs contains approximately 20-60 eggs (e.g, Hanning 1979, Perry 1974, Turner 1996, Darby et al. unpublished data). A single egg is laid approximately every 2-4 minutes for up to several hours (Hanning 1979). Individual eggs are 3-6 mm in size (Turner 1996). They are wet, soft, and a pink/salmon color when laid, but become hard

(calcified) and turn pinkish-white to grayish-white when they dry. The period of incubation is temperature dependent (Hanning 1979 [p. 69]). Eggs hatch in about 16-22 days (Hanning 1979, Perry 1974). Hanning (1979) found that most eggs hatch at night or in the early morning, which could assist in avoiding desiccation if hatchlings do not drop directly into the water.

Female apple snails lay eggs about 10-20 cm above the water line (Turner 1996, Hanning 1979, O'Hare 2010, Darby unpublished data). However, heights of up to 2.0 meters have been observed on cattail (*Typha*; Hanning 1979). Turner (1996) found that in marsh habitat in BCWMA, the emergent plant species most used for oviposition were sawgrass, swamp lily (*Crinum americanum*), pickerelweed, and lance-leaved sagittaria (*Sagittaria lancifolia*). Depending on the plant species, snails can lay eggs on any emergent plant structure, including stems, petioles, leaves, and flower stalks. Turner (1996) associated oviposition with an apparent preference for emergent plant parts > 6 mm in diameter at the water's surface. Egg height above water did not differ among vegetation types, nor did clutch size (Turner 1996). Bennetts et al. (1988) and Darby et al. (1999) found eggs concentrated on plants along the sawgrass ecotone (bordering prairie or slough), with fewer eggs found in interior sawgrass patches. Bramburger et al. (2012) sampled egg clusters for 10 months along transects in ENP that were primarily sawgrass-dominated marsh.

In one of the few studies on the topic, Hurdle (1974) examined the number of egg clusters produced per female. He observed two female snails in enclosures in impoundments for several months. One was kept with a male, and the other without a male. The snail pair was observed mating on multiple occasions. This female produced 21 egg clusters during observation— all fertile. She produced at least 21 egg clusters from mid-March to late July (when she was found dead in the enclosure). The isolated female laid at least 10 fertile egg clusters before producing infertile eggs. She was temporarily removed and allowed to mate. Once returned to the enclosure, she again produced fertile eggs (but the fertility of all subsequent clusters was undetermined); the entire period over which she laid eggs in the enclosure (until her death) was mid-March to early September; she produced a total of 25 egg clusters. Two important points emerged from this work: the first was that females may produce multiple clusters of eggs from only one mating, and the second was that females produce many clusters of eggs during the egg-laying season. Hurdle (1974) reported that a cluster of eggs was laid about every three to four days, with up to 3 clutches produced per week. Hanning (1979, p. 134) reported that females in mesocosms *in situ* laid an average of about one clutch per week; he did not report the total number of clusters produced per female.

Egg clusters or individual eggs may be damaged naturally in various ways: 1) from wind or waves damaging the plants on which eggs were laid; 2) from female snails hitting older, lower clutches when they complete egg laying and drop back to the water; and 3) from birds (e.g., boat-

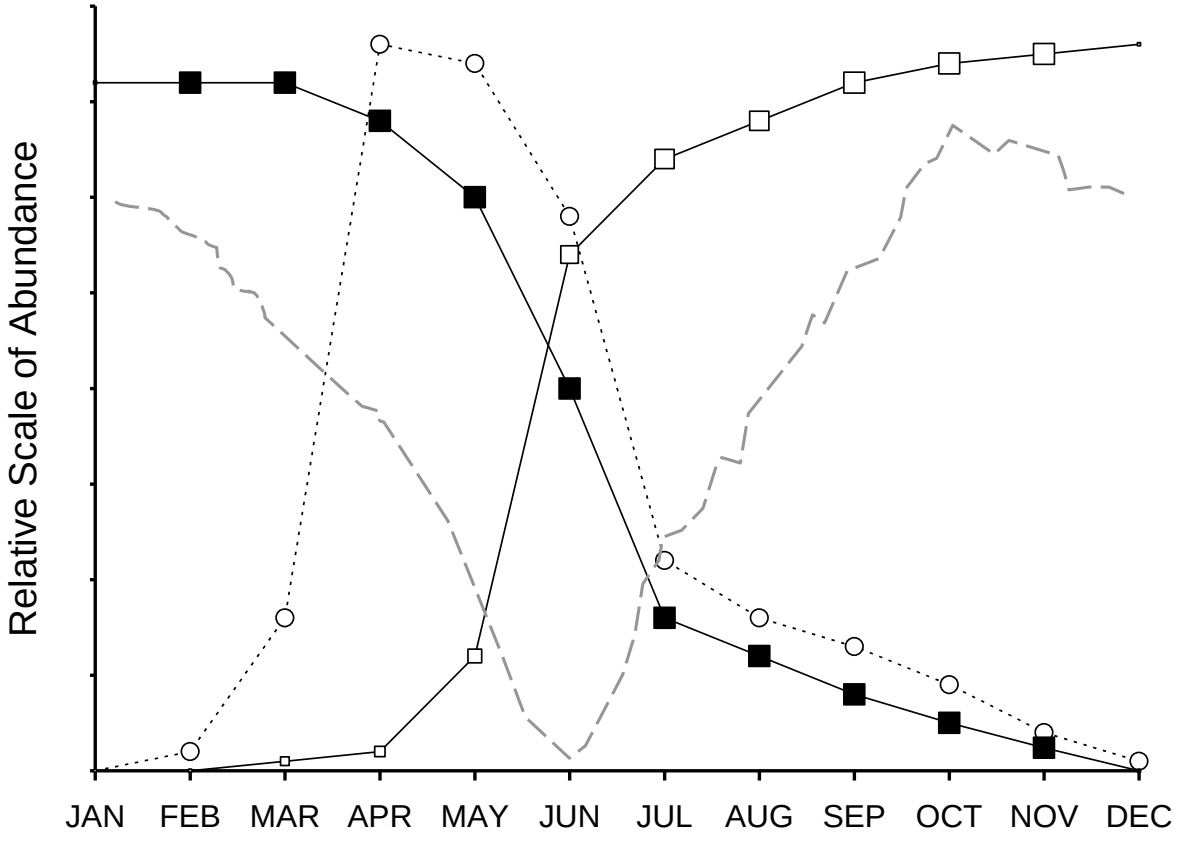
tailed grackles) perching on plant stems containing eggs (Snyder and Snyder 1971; Hanning 1979). Herbicide applications may also result in egg-bearing vegetation falling into the water (P. Darby, pers. observ., LKISS and Wacissa Springs). Laboratory studies on the effects of submergence on embryonic survival and growth showed that submergence in water slowed the rate of development and increased mortality (Turner 1998). More information on this topic will be provided in Chapter 6 in relation to water management. Also see the "Predators" section later in this chapter for a discussion of predation of eggs.

LIFE CYCLE AND BREEDING SEASON

It should be noted that most of the data cited in this section came from studies of Florida apple snails on LOKEE, Silver Springs, SJM (= BCWMA), LKISS, LTOHO, LISTOK, GWP, WCA1, WCA2B, WCA3A, and WCA3B. See the end of this section for the results of an egg cluster study in ENP.

Florida apple snails have a life span of 1-1.5 years (Hanning 1979, Ferrer et al. 1990, Darby et al. 2003, Darby et al. 2008). In general, the majority of young apple snails: hatch in the spring; grow during the spring, summer and fall; overwinter; reproduce the following spring; and die late in the dry season or early in the wet season after completing reproduction (Hanning 1979, Darby et al. 2008). In Darby et al.'s conceptual model of the seasonal dynamics of apple snail abundance at various life stages (eggs, juveniles, adults) (see Figure 4-4), reproductive adults are predominant in the population from January until June. They are then gradually replaced by young of the year snails as the adults die and the young grow to adult size. Hanning (1979) documented a shift in snail size-frequency distribution to smaller snails in summer, consistent with the conceptual model. Snails hatch out at approximately 3-5 mm. They grow approximately 10-13 mm per month (during the first two months; Hanning 1979, Glass and Darby 2009), so that snails hatched in the spring reach adult size by early- to mid-summer (Darby et al. 2008). Larger snails are generally older snails, but once snails attain shell lengths of approximately 30 mm, there is no definitive way to estimate age or reproductive status based on external morphology (Darby et al. 2008). Temperature, food, and water depth influence growth rates in other *Pomacea* snails (see Cowie 2002), but their effects on Florida apple snails have not been reported. Although hydrology effects on snails have received the most attention in the literature (largely driven by interest in water management), the aforementioned influences (and their interactions) should not be overlooked as significantly affecting Florida apple snail abundance and distribution; they have shown to be significant in other snail species (e.g., see Lodge et al. 1987).

Figure 4-4. Annual cycle of the relative abundances of apple snails hatched in the previous year (those that over-wintered and entered the new year as adults) (■), young of the year snails (those that hatched from egg clusters in the current calendar year) (□), and egg clusters (O). The relative size of the young-of-the-year symbol (□) represents the change in average size of this group of snails throughout the year. Standardized water stage values (—) reflect minimum and maximum 20-year average daily water stage (1985-2004) for six wetlands: LKISS, LOKEE, BCWMA, WCA1, WCA2B, and WCA3A. Note that the timing of peak egg abundance may shift (or be suppressed) due to cool temperatures or extreme dry or wet conditions (see text for details). Figure (with water stage values added), used with kind permission from Springer Science + Business Media: Wetlands, Dry down impacts on apple snail (*Pomacea paludosa*) demography: Implications for wetland water management, Volume 28, 2008, Pages 204-214, P.C. Darby, R.E. Bennetts, and H.F. Percival, Figure 1, © 2008, The Society of Wetland Scientists.



The timing of reproduction and the subsequent post-reproductive die-off occur over a small window of time each year (Darby et al. 2008). As previously mentioned, the majority of egg-laying occurs from March through October, with a peak in April, May, or June (Hanning 1979, Odum 1957, Darby et al. 1999, and Darby et al. 2008). Darby et al. (2008) estimated that almost 80% of egg production occurs during April-June. The Florida apple snail's life cycle ends in a post-reproductive die-off, with the majority of adults dying between approximately May and August (Darby et al. 2003, Darby et al. 2008). Darby et al. (2003) saw the greatest adult mortality rates in May and June (in both free ranging and captive snails).

The peak period of oviposition described here may be affected by environmental factors. For example, a spring dry down (depending on its timing and duration) may eliminate oviposition, so the peak in production may shift to summer (Darby et al. 2008). The initiation of oviposition in the spring may be delayed by relatively cool temperatures (Hanning 1979). Relatively high water (depths greater than approximately 40 to 60 cm) may also delay egg laying, resulting in a shift in peak reproduction, as well as an overall decrease in the total number of eggs produced for a population (Darby et al. 2005; also see Chapter 6 and recommendations for additional research, Chapter 11).

As noted at the beginning of this section, most (but not all) of the information collected on egg-laying has been from lakes and relatively long hydroperiod wetlands. A recent study monitored egg-laying in depressions in seasonal wetlands (inundated 6-8 months) in ENP (Hole-in-the-Donut region, south of Long Pine Key) that are typically not inundated until the rains begin around June (O'Hare 2010). Over five years of monitoring, the researcher found that the oviposition peak usually occurred in early July and egg production tapered off through the summer and fall. In several sites, O'Hare also observed greater total egg clusters in years when the wet season began earlier than typical in this part of the Everglades (e.g., in April). This pattern is consistent with observations by Darby et al. (2008); snails do not mate or lay eggs in dry down conditions, but emerge from aestivation to lay eggs when water returns. Note that peak egg production was also shifted to summer as a result of relatively high water conditions in March-May (i.e., greater than approximately 40-60 cm; Darby et al. 2005).

AESTIVATION AND DRY SEASON SURVIVAL

The majority of ampullarid snail populations live in shallow tropical and subtropical wetlands that periodically dry out (water table below ground level). *Pomacea* and *Pila* snails are capable of surviving dry down conditions for three months to over two years (Cowie 2002). Snails survive dry down conditions through aestivation— a state of inactivity and reduced metabolic activity that allows an animal to conserve moisture and energy stores. During aestivation, snails may bury themselves

partially (typical for the New World genus *Pomacea*) or completely (up to 1 m deep for *Pila*) in the substrate (Cowie 2002). The Florida apple snail exhibits a limited capacity to burrow, often not burrowing at all, or leaving a portion of the shell exposed (Darby et al. 2008).

Up through the 1990s, Florida apple snails were thought to have little dry down tolerance. However, information on their dry down tolerance was limited to a few studies and most often based on indirect evidence (e.g., snail kites abandoning wetlands that had gone dry; see Darby et al. 2003). Declines in abundance were reported in relation to low water levels in the Everglades (Kushlan 1975). Turner (1994) observed mortality rates ranging from 67-90% during 7 to 30 days of aerial (dry) exposure in the lab. Little (1968) noted that the Florida apple snail's mortality rate was higher than another apple snail species (*Pomacea lineata*), but provided no details about survival over time. However, after reviewing reports by Hanning (1979) and Ferrer et al. (1990) that the Florida apple snail had a 1 to 1.5-year life span, Darby et al. (2003) suggested that the previous studies on dry down tolerance were confounded by an annual adult die-off. Laboratory and field studies conducted by Darby et al. (2003 and 2008) showed this to be the case and found that Florida apple snails survived weeks to months in dry down conditions. Significant proportions of pre-reproductive, adult-sized snails survived at least 6 weeks (94% of snails) and 12 weeks (71%) in dry down conditions (Darby et al. 2008). However, dry downs that exceed the snail's capacity to aestivate can substantially affect the snail population in the next year or more (Darby et al. 2008). Further details of these studies are provided in Chapter 6 in the context of water management.

Peak oviposition most often occurs in the dry season, and it often precedes an ensuing dry down. Consequently, young of the year snails in some years may be faced with dry downs when only weeks old. Although not as tolerant as adult-sized snails, juvenile snails do have the capacity to survive drying events 4-8 weeks in duration, depending on size (Darby et al. 2008; additional details on juvenile dry down survival are provided in Chapter 6). It appears that the reproductive cycle of the Florida apple snail is timed to allow young snails to grow to a large enough size to survive dry conditions in the dry season in which they hatched (Darby et al. 2008), as has been reported for other apple snail species (Burky 1974, Burky and Burky 1977, Haniffa 1978a and 1978b). However, naturally-occurring dry downs, or poorly-timed managed drawdowns, have the potential to dramatically affect apple snail egg-laying and recruitment of juveniles into the population (Darby et al. 2004, 2008).

PREDATORS

All size classes of Florida apple snails, from 3-6 mm hatchlings to >40 mm adults, are targeted by predators. Snail kites generally capture Florida apple snails that are 30 mm in size and larger, with

20 mm the approximate minimum size (Sykes 1987b). In addition to being the nearly exclusive prey of the snail kite (Snyder and Snyder 1969), the adult-sized snails comprise more than 75% of the diet of the limpkin (*Aramus guarauna*; Cottam 1936, Snyder and Snyder 1969). Other avian predators include the white ibis (*Eudocimus albus*; Kushlan 1974) and the boat-tailed grackle (*Cassidix mexicanus*; Snyder and Snyder 1969). Alligators (Fogarty and Albury 1967, Delaney and Abercombie 1986), redear sunfish, also known as "shell crackers" (*Lepomis microlophus*; Chable 1947), and soft-shelled turtles (*Trionyx ferox*; Dalrymple 1977) also prey on the apple snail. Snyder and Snyder (1971) observed crayfish (*Procambarus* sp.), loggerhead musk turtle (*Sternotherus minor*) and aquatic insects (water bugs, *Belostoma* sp.; dragonfly naiads, *Coryphaeschna ingens*; and diving beetles, *Dytiscus marginalis*) eating the native apple snail.

In a preliminary lab study using field-collected fish, Darby et al. (2009) found that the following species consumed apple snails approximately 4-10 mm in diameter: Mayan cichlids (*Cichlosoma urophthalmus*), redear sunfish, Seminole killifish (*Fundulus seminolis*), and bluegill (*Lepomis macrochirus*). A greater siren (*Siren lacertina*) also consumed a snail. Several other species tested (largemouth bass [*Micropterus salmoides*], blue spotted sunfish [*Enneacanthus gloriosus*], and golden top minnow [*Fundulus chrysotus*], did not eat snails in the lab, but ate other food offered. In subsequent lab experiments using a larger range of snails, redear sunfish consumed snails 5-19 mm in size, and the few Mayan cichlids (n=3) that were tested ate snails up to 20 mm in size. Non-native Mayan cichlids appeared able to consume larger snails compared to similarly-sized (total length) native redear sunfish.

Smaller predators (i.e., crayfish [17-35 mm in carapace length], small turtle species, some fish) consumed snails ranging from 4-11 mm in diameter in a lab setting (Darby et al. (2009). Musk (*Sternotherus odoratus*) and mud (*Kinosternon bauri*) turtles (about 40-90 mm in carapace length) readily ate snails up to 10 mm in size. The turtles also consumed larger snails (up to 22 mm in size), but some of these snails were eaten by being pushed into aquaria corners; it is uncertain whether this technique would be used under natural conditions. Darby et al. (2009) reported that predation on hatchling and juvenile snails by these smaller predators may be significant in regulating snail populations (see Chapter 6, as predation pressure is influenced by hydrology).

Predation is one of several reasons that have been suggested for apple snails laying terrestrial eggs (see review in Hanning 1979). Laying eggs out of the water may be a way to avoid aquatic predators (Clench 1959, Hanning 1979). There have been few reports of animals consuming Florida apple snail eggs, and there is evidence from both field and laboratory observations for the distastefulness of the eggs (Snyder and Snyder 1971). Recent work by Dreon et al. (2010) characterized egg proteins responsible for predator defense (antinutritive/antidigestive, neurotoxic,

and aposematic [warning coloration] components) in *Pomacea canaliculata* eggs. The eggs of this exotic species, which are probably also unpalatable, have only one known predator— the fire ant *Solenopsis geminata* (Dreon et al. 2010). Kushlan (1978) reported an observation of the coneheaded grasshopper (*Neoconocephalus triops*) consuming Florida apple snail eggs during the early stages of egg development, but he was not sure how the grasshopper gained access to the contents of the egg (i.e., scavenging on a damaged egg, or causing the primary damage). In counting thousands of egg clusters, Darby et al. (UWF, pers. obs.) have never seen evidence that eggs were preyed upon.

NON-NATIVE APPLE SNAILS AND THEIR POTENTIAL THREATS

As early as the 1980s there were at least two species of non-native apple snails reported in peninsular Florida: *Pomacea bridgesei* and *Pomacea canaliculata* (Thompson 1984). *Marisa cornuaurietus*, also a member of the Ampullariidae family, but not an "apple snail," was also well established in southern Florida by the 1980s (Thompson 1984). Until recently, there seemed to be little concern for potential impacts of these introduced ampullarids; they occurred in isolated populations, primarily in man-made aquatic habitats, and there was no indication of harm to habitats or wildlife. From 2000-2004, that perspective changed when a non-native snail, thought to be *P. canaliculata*, rapidly spread in Florida. This snail had recently gained world-wide attention as highly invasive and destructive to wetland-based agriculture (rice and taro; Cowie 2002). Due to issues with identification, previous reports of *P. canaliculata* damaging wetlands most likely should have been attributed to *P. insularum.* Rawlings et al. (2007) used mitochondrial DNA to differentiate between species and clarified identification of non-native *Pomacea* in the U.S. The work established that at least three species of exotic apple snails occur in Florida: 1) *Pomacea insularum*, (previously thought to be *P. canaliculata*), 2) *Pomacea haustrum*, and 3) *Pomacea diffusa* (previously thought to be *P. bridgesii*; Rawlings et al. 2007). More recently, preliminary genetic data indicated the presence of an isolated population of *P. canaliculata* in northern Florida (Jenn Bernatis, FFWCC, pers. comm.).

Concerns over potential impacts to native apple snails, their habitats, and their predators are warranted. Apple snails from the genus *Pomacea* have been shown to have negative impacts on agriculture, habitats, and human health (via trematode parasites) in other regions of the world (Cowie 2002, Carlsson et al. 2004). However, for the most part, dramatic or widespread impacts such as those seen elsewhere have not been observed in Florida to date, although few targeted studies of exotic apple snails have been conducted. To date, no studies in Florida have connected declines in snail kite or apple snail abundance, or any other kite or snail demographic metric, or degradation of kite or snail habitat, to the invasion and spread of exotic *Pomacea*. However, observations and effects of adult and juvenile snail kites foraging on *P. insularum* on one Florida lake have been

documented (as discussed in Chapter 3). Exotic snails proliferating in and impacting vegetation on several small lakes or ponds (not inhabited by snail kites) in central and northern Florida have also been reported, as discussed below.

A large population of *P. insularum* has become established on LTOHO, where snail kites are known to forage and nest. As discussed elsewhere in this report, LTOHO has been one of the most important wetlands for kite nesting in the last several years (e.g., Reichert et al. 2011a and b). The exotic snail in LTOHO was first discovered in 2001 in Goblet's Cove, with its eggs initially found along the deepwater cattail regions (Darby 2006). It was presumed that the introduction originated with aquaria release into the C31 Canal, which empties into Goblet's Cove. During 2002 and 2003, exotic eggs were found adjacent to the C31 and along the southern and western littoral zones of Goblet's Cove. In 2003, crews with 1-m^2 throw traps found two exotic snails in the shallow littoral zone in Goblet's Cove (Darby 2006). By 2005, exotic eggs were found 6 miles away along South Steer Beach. Kitchens et al. (2008) recorded exotic snails captured in funnel traps and reported site occupancy (as compared to densities). They captured no exotics in 2003, but in 2005 (1 year after lake drawdown and habitat management), site occupancy increased to 45%; occupancy increased to 83% by 2006. Since 2003, snail kites have been foraging over areas which contain exclusively non-native snails (Darby 2006, Darby et al. 2007, Cattau et al. 2010). It should be noted that the density of native snails on LTOHO was low prior to *P. insularum* expansion, most likely due to poor habitat structure and unsuitable hydrologic conditions (Darby 2006).

At this time, nothing is known about the potential impact of parasites harbored by *P. insularum*. Ampullariids serve as intermediate hosts of vertebrate parasites that include nematodes, trematodes and schistosomes (Cowie 2002). Some species of apple snails (including *P. insularum*; Aquatic Nuisance Species Task Force 2009) are known to harbor the rat lungworm nematode (*Angiostrongylus cantonensis*; Ghesquiere 2011). Tim Collins and Paul Sharp (Florida International University) and Phil Darby (UWF) have initiated a survey of parasites found in native and exotic snails.

There is very little information pertaining to direct effects of the exotic snail on native snails, although invasive snails from the genus *Pomacea* are responsible for declines of native snail species in southeast Asia (Cowie 2002). *P. canaliculata* have demonstrated their appetite for other gastropods and their eggs (Cowie 2002), although this has not been observed in Florida. A laboratory study by Conner et al. (2008) indicated that the mere presence of *P. insularum* inhibited the growth and survival of juvenile *P. paludosa* (possibly via a density-dependent growth effect). There is no evidence that the decline in the LTOHO native snail population was due to the presence of *P. insularum* (native snails were largely absent prior to invasion of the exotic; Darby 2006).

Habitat structure can be altered dramatically by herbivorous snails (Bronmark 1989). Grazing by *Pomacea* snails has degraded wetland habitats and impacted agricultural regions in Southeast Asia, California, Texas, and Hawaii (Cowie 2002, Carlsson et al. 2004, Carlsson and Lacoursiere 2005, Ramakrishnan 2007, Rawlings et al. 2007). [As stated earlier, it is now thought that much of the damage attributed to *P. canaliculata* may have actually been due to *P. insularum* (Rawlings et al. 2007).] Carlsson and Lacoursiere (2005) described "intense herbivory" by *P. canaliculata* that resulted in significant reductions in overall aquatic plant biomass. Based on laboratory trials, Baker et al. (2010) concluded that feeding rates of *P. insularum* would result in significant destruction of native and non-native aquatic plants in Florida. *P.insularum* (reported as *P. canaliculata*) is described as voracious, readily consuming almost any aquatic plant, but being especially attracted to "less coarse plants" such as tape grass (*Vallisneria americana*; Brown 2005). There are several reports of the exotic consuming both submerged and emergent species on small lakes or ponds in central and northern Florida (see Brown 2005, Schmidt 2005, Van Dyke 2010). However, Darby (2006) reported plant community composition similar in littoral zone plots with and without *P. insularum*; the same emergent macrophytes and SAV were encountered with nearly equal frequency regardless of the presence of the exotic snail. Despite the spread of *P. insularum* throughout LTOHO and occupancy for ~10 years, there is no evidence of widespread destruction of wetland habitats on the lake at this time. However, it is possible that negative impacts to LTOHO habitats could develop or be detected in the future, and it is possible that a population of the exotic in other lake or wetland systems could lead to different or more rapid ecological impacts there.

Many aspects of the ecology of *P. insularum* are not known at this time, and their impacts on Florida wetlands wildlife remain unclear. In the meantime, exotic snails are spreading, and we recommend that some type of prevention and early detection program be implemented to attempt to slow their spread. It is imperative that further research be undertaken to assess potential impacts to snail kites, native snails, and habitats, as well as aid in sound management decisions (See Chapters 10 and 11 for recommendations).

CHAPTER 5: SNAIL KITE DEMOGRAPHY AND RELATIONSHIPS TO HYDROLOGY AND VEGETATION

INTRODUCTION

This chapter addresses trends in snail kite abundance and distribution, and their relationships to hydrology and vegetation. How water levels and vegetation influence movements, nesting, and foraging are also major topics of this chapter. Direct relationships between kite foraging and snail availability (a function of snail density and kite access to the snails), are presented separately in Chapter 7.

Hydrology has been reported as the most important environmental variable affecting kite populations (reviewed by Sykes et al. 1995, Bennetts et al. 2002). During drought periods (and associated drying out of wetlands) researchers have found: snail kite populations can experience decreased survival (Beissinger 1986, Takekawa and Beissinger 1989, Martin et al. 2006a) and/or reproduction (Snyder et al. 1989a); apple snails can become unavailable to kites (Sykes et al. 1995); and apple snail populations can decrease (Kushlan 1975), depending on the extent and duration of the dry down period (Darby et al. 2008). Drought conditions have received the most attention among a range of hydrologic conditions, but high water years have also received some attention (e.g., Bennetts et al. 2002). Although relatively high water years have been reported as favorable for kite nesting (Bennetts et al. 2002, Beissinger 1995), excessive water depths and/or prolonged inundation can present undesirable conditions for kites (Sykes 1983b, Bennetts et al. 1994, Bennetts et al. 2002). Water depths deeper than 1-2 m can: lack sufficient oxygen for apple snails (Hanning 1979); limit apple snail food or access to emergent vegetation used for climbing to the water's surface to breathe air (Bennetts et al. 1988, Bennetts et al. 2002); or adversely affect the structure of nesting or foraging habitat (Bennetts et al. 1998a, Kitchens et al. 2002). Over time, structure important for nesting (e.g., woody substrates) and foraging (i.e., emergent vegetation) can be degraded as a result of prolonged inundation (Bennetts et al. 1994, 1998a, Kitchens et al. 2002). Given the numerous possible hydrologic scenarios that could impact snail kites, and a lack of empirical data associated with many of them, computer simulations of kite demography that include hydrologic inputs have been developed as a potential tool to evaluate alternative water management scenarios and their impacts on kites. A description of these computer simulation tools appears in Chapter 8.

SNAIL KITE DEMOGRAPHIC TRENDS AND ASSOCIATIONS WITH HYDROLOGY

Accounts of the abundance and distribution of snail kites in Florida date back to 1932, with sporadic records dating back to 1844 (see Sykes 1984); however, access to potential kite use areas was limited, and systematic surveys were not conducted, so it is difficult to interpret reported observations. Systematic counts and nest checks were initiated in 1969, and since that time the levels of effort, monitoring protocols, and analytical tools have changed significantly. Here we present a chronological review of efforts (starting in 1969) to quantify snail kite survival, recruitment, and population size, and describe the modern computational basis upon which snail kite demography is now characterized.

Annual Count Data and Baseline Estimates of Survival and Recruitment

Snail kite population estimates in 1969-1994 were based on the annual fall count, a survey of all wetlands known during that period to support kites (also see Chapter 3). Nest monitoring and juvenile banding was also conducted. Despite some inherent problems associated with the count (once described as a "census," see below), estimates derived from 1969-1979 data, collected primarily by Paul Sykes (USFWS), provided initial insight into kite demography. Based on Sykes' data, Nichols et al. (1980) characterized the snail kite as a long-lived species (>18 years, based on birds that had been banded up to that time), with relatively high adult annual survival rates (>0.9). Nichols et al. estimated juvenile survival rates at 0.58. From 1969-1979, the snail kite count rose from ~100 to over 400 kites (Sykes 1983b). Using a deterministic model, Nichols et al. (1980) estimated an annual population growth rate (λ) of 1.054; however, this estimated λ was likely influenced by increased effort to survey kites (Bennetts et al. 1999a), so that the apparent population growth estimate was likely biased high due to counting a greater proportion of the population.

In their population model, Nichols et al. (1980) assumed a first breeding age of 3, which later was found to be too high (see below). Although snail kites can, at times, fledge up to 4 birds per nest (Sykes et al. 1995, Dreitz and Shannon 1998), lifetime fecundity (when factoring in poor recruitment years) was relatively low in the 1970s (0.44 females produced per nest, based on 183 nests per Nichols et al. 1980). Sykes (1987c) found that annual variation in reproductive metrics was high (data from 1968-1978); total number of young fledged per year included 0 in a drought year (1971), and otherwise ranged from 8 to 22. Nest success ranged from 17 to 85%. The capacity for short-term, high nest success rates is consistent with a long-lived species that relies on wetlands with boom or bust (wet vs. dry) cycles of apple snail availability (Beissinger 1986). Interannual variation in age structure reflected changes in recruitment of juveniles, not changes in

adult survival. Assuming high reproductive capacity for females up to 18 years and older, Nichols et al. (1980) concluded that the snail kite population could persist for years with little to no breeding associated with poor habitat (emphasis on dry down) conditions. Their estimated population "half-life" was 9.5 years (i.e., the time it takes for the kite population to drop by 50% after successive years of poor recruitment). Nichols et al. (1980) concluded that snail kite population persistence relied on relatively stable and high adult survival rates, with population level fluctuations primarily reflecting changes in female fecundity as driven by habitat quality (e.g., apple snail availability).

By 1980, the annual kite count had reached its high, up to that point in time, of approximately 650 birds (as reported in Rodgers et al. 1988; see also Figure 3-7, solid squares). A drought year in 1981 resulted in few observer days and a kite count of only 109 birds (Rodgers et al. 1988). Undoubtedly the count was influenced by dispersal of kites from main survey areas (see Rodgers 1983). Through the remainder of the 1980s, statewide kite counts ranged from 300 to over 600 birds and appeared relatively stable (see Figure 3-7). The drought years of 1989-1990 appeared to have had little effect on the kite count. From 1991 to 1994, Bennetts et al. (1999a) counted from 400 to 954 snail kites (see Figure 3-7).

Bennetts et al. (1999a) described limitations of the annual count (originally intended to be a census, an attempt to count all snail kites in Florida) to estimate snail kite abundance, survival rates, and population growth rates. They noted that detection probability, and consequently the number of snail kites counted, likely varied widely due to observer differences (e.g., due to experience), observer effort, site effects (e.g., habitat types), water levels, etc. R. Bennetts also pointed to inconsistency in areas surveyed within and among wetlands (see Bennetts Comment Matrix, Comment # 6, Appendix B). As a result, it was difficult to distinguish an increase in the snail kite population from observer or other effects (e.g., an increase in survey effort; Bennetts et al. 1999a). Because early monitoring efforts had fewer resources to invest in the survey, the low kite counts prior to 1980 likely reflected relatively low numbers of observer days; these counts probably substantially underestimated the kite population. Adjusting the annual count for number of observer days, water level, and other effects, greatly increased the total estimated count compared to the raw counts for the Florida kite population in approximately half of the years from 1969-1994 (Bennetts et al. 1999a, Figure 3-7). The annual count was discontinued in 1994.

Telemetry-Based Studies

From 1992 to 1994, Bennetts et al. (1999b) outfitted 271 snail kites (164 adults, 117 juveniles) with radio transmitters. The radio transmitters were equipped with mortality signals

(i.e., the radio pulse rate changed after it remained still for 6-8 hours). Kite locations and status (dead / alive) were monitored biweekly. Survival based on telemetry data was compared to annual survival rate ($\hat{S}$) derived from banding data (using Cormack-Jolly-Seber (CJS) models, also see next section). [Note that some of the publications discussed in this section use the symbol "$\hat{\phi}$" for survival; others use "$\hat{S}$", as we will here]. Adult $\hat{S}$ ranged from 0.86-0.96 (telemetry data, 1992-1994, 3-yr average = 0.89) with no significant difference over time. The CJS model yielded a constant $\hat{S}$ of 0.86 (1992-1996). Bennetts et al. (1999b) found no difference in apparent survival between adult (>2 years old) and subadult snail kites (age 365 days to 2 years); as a result, they defined an "adult" as >1 year old. As Nichols et al. (1980) had reported, juvenile survival was significantly lower (0.44-0.87, telemetry estimates; 0.24-0.61, CJS estimates for 1992-1996) than that of adults. [The survival estimates from Bennetts et al. (1999b) were made during a relatively wet period for central and south Florida wetlands, so the impact of drought on survival could not be assessed]. The discrepancy between juvenile $\hat{S}$ derived from telemetry vs. banding data was probably due to the censoring of a higher-than-desirable proportion of juvenile kites in the telemetry study (Bennetts et al. 1999b). Censoring is the removal of data on radio-tagged birds from a sample when the transmitter signal is no longer detected (White and Garrott 1990). Thirty-five to 40% of juvenile kite data points were censored in 1992-1993; in 1994 the number censored dropped to ~10-15% due to increased effort and success in tracking down mortality signals. The authors concluded that the 1992-1993 apparent $\hat{S}$ estimates from telemetry were biased high due to censoring of juveniles whose deaths were not confirmed. The telemetry data indicated no effect of region on adult or juvenile survival (comparing WCAs, LOKEE, LKISS, and USJM). However, the CJS juvenile $\hat{S}$ estimates were significantly different between regions, although no one region consistently yielded higher juvenile $\hat{S}$ compared to others. The authors concluded that bearing radios did not decrease snail kite $\hat{S}$, as supported by comparison to the CJS-derived estimates. Based on the bias associated with telemetry-based survival estimates, especially for juveniles, they recommended mark-resighting be used for annual survival estimates.

Bennetts and Kitchens (1999b) used the same radio telemetry data described above to estimate within-year survival. They estimated survival in 4-month intervals (January-April, May-August, September-December). The highest risk of mortality for juveniles bearing transmitters occurred in the first 4 months of being outfitted with a radio ($\hat{S}$ dropped from 1.0 to 0.7). Juvenile survival may have been lower due to less experience, predation (including at the nest), and no experience finding flooded marshes when local ones went dry. From this point forward, juvenile $\hat{S}$ leveled off and few young-of-the-year snail kites died. Both adults and juveniles experienced

an approximate 5% increase in mortality from January-February. The authors speculated that owl predation increased in winter, as willows lost their leaves and rendered roosting kites more vulnerable. We would add that cold fronts may reduce snail activity to a point where reduced food availability may impact kites (Stevens et al. 2002). Cary (1985) observed that no snails were captured by snail kites foraging in WCA3A when air temperatures were between 0 and 10 °C. As air temperatures increased to 11 to 20 °C, capture rates rose to 0.4 snails per 30 minutes; they further increased to 1.3 and 2.6 snails per 30 minutes as temperatures increased to 30 °C and 40 °C, respectively (Cary 1985). Periods of cold temperatures that result in no or few snail captures may energetically stress kites and contribute to lower winter survival as reported by Bennetts and Kitchens (1999b).

The 1992-1995 telemetry data confirmed what had been alluded to based on older data (data from Sykes and Rodgers as presented in Beissinger [1995])— that the snail kite population in Florida is one contiguous population, not a collection of populations established in different wetland units throughout Florida (Bennetts and Kitchens 1997b). As stated by Beissinger (1995), kites "move fluidly between Lake Okeechobee, the Central Lakes region, and the conservation areas." Bennetts and Kitchens (1997a) reported monthly movement probabilities (i.e., birds leaving a wetland unit) of birds wearing transmitters of 0.25 for adults and 0.20 for juveniles. Their ability to move and find alternative food supplies helps ameliorate the negative impacts of drought and other environmental conditions that reduce apple snail availability. Additional details on snail kite movements are presented later in this chapter.

From Annual Count to Statistically Robust Sample

In 1992, Bennetts and Kitchens (1997a) initiated a mark-resighting protocol, which by design estimated detection probabilities ($\hat{p}$; also known as resighting probabilities), as a way to monitor the snail kite population. From over 20 years of observations and attempts to count the entire kite population, it became increasingly apparent that annual surveys missed many kites (Bennetts et al. 1999a), and that $\hat{p}$ could vary for a number of reasons. For example, birds may be missed in a survey of wetlands with numerous tree islands or willow heads (low $\hat{p}$), as compared to more open habitats (e.g., lakes, higher $\hat{p}$), and kites may move and occupy wetlands not included in the survey. Demographic estimates derived from mark-resighting studies are more reliable, statistically defensible, and adjust for variation in resighting probabilities that can bias count data (Nichols 1992, Bennetts et al. 1999a, Martin et al. 2007a). Consecutive years of mark-resighting data also provide estimates of survival and recruitment.

All of the analyses from band-resight data discussed below were based on an open population model (C-J-S, see Bennetts and Kitchens 1997a), one in which the population, on an annual basis, experiences mortality, recruitment and/or migration into and out of the study area. Although the annual banding-resighting survey evolved somewhat over the years, the essential elements are: 1) the survey occurs from March 1- June 30 (with slight annual variation for logistical reasons); 2) although the bulk of the data depends on birds banded since 1992, some older banded birds (e.g., by Sykes, Rodgers, Beissinger) have been included in the survival and population estimates; 3) every year, each wetland included in the survey (WCAs, Kissimmee Chain-of-Lakes, LOKEE, etc.; see Chapter 2 for a complete list of locations) is surveyed on six separate occasions (at approximately 2 to 3-week intervals) to complete the annual survey (i.e., the six individual surveys are combined for the annual estimates); and 4) every sighted snail kite is categorized into one of three groups (i.e., marked, unmarked, or unknown [if the band status cannot be determined]). Since the survey occurs over a 4-month period each year, and snail kites move frequently between wetlands (25% of adult kites move each month per Bennetts and Kitchens [1997b]), temporary emigration must be considered, including to non-surveyed, or "peripheral sites." As described in Chapter 2, young kites are banded at approximately 24 days of age during nest monitoring activities.

Since 1997, the population estimates have been based on a superpopulation approach, which accounts for the fact that individual snail kites may enter the survey population from un-surveyed areas (again, due to the nomadic tendencies of kites) during the course of the 6-occasion, 4-month, annual survey. The superpopulation estimate is for the statewide snail kite population. For details on the superpopulation approach, see Williams et al. (2002, p. 508) and Dreitz et al. (2002a). For more details on the annual kite survey and analyses to estimate the kite population, see Bennetts and Kitchens 1997a, Dreitz et al. 2002a, Martin et al. 2007a). The CJS-based superpopulation analysis produces an estimate of detection probability ($\hat{p}$) and superpopulation size ($\hat{N}$); population growth rates (λ) are estimated from two successive annual estimates of $\hat{N}$ ($\lambda = N_{t+1} / N_t$, *where t=year*). Survival rates ($\hat{S}$) (called apparent survival, since emigration from the surveyed area factors into the survival estimate) are also derived from CJS-analyses of the band-resight data.

Survival and Population Trends: A Relatively Wet Era, 1992-2000

Dreitz et al. (2002a) published the first population growth rates (λ), and also reported survival estimates, for snail kites using the mark-resighting protocol. Annual survey resighting

probabilities ($\hat{p}$) varied from 0.28-0.32. Their data were collected during a relatively wet period for most of central and south Florida (see Figure 2-2 and Appendix C), so $\hat{p}$ was not affected by limited access to wetlands due to dry down conditions.

Dreitz et al. (2002a) reported little change in the estimated population size from 1997 to 1998 (3,145 to 3,136 birds), a slight increase (but overlapping confidence limits) in 1999 (3,577 birds), followed by a decrease in 2000 (2,772 birds). Population growth rates (λ) were 1.00, 1.14, and 0.78, with all confidence limits overlapping, from 1997-1998, 1998-1999, and 1999-2000, respectively. Overall, these were relatively wet years in snail kite-occupied wetland units (i.e., no drying events). There appeared to be a decline after 1999. Dreitz et al. reported constant annual survival rates (combined juveniles and adults) from 1997-2000 (0.74 ±0.04 SE; separate adult and juvenile survival rates were not reported in Dreitz et al. 2002a). From 1992-1996, Bennetts et al. (1999b) reported annual adult $\hat{S}$ at a constant 0.86, with juvenile $\hat{S}$ varying year to year (0.24 to 0.61; 0.45 overall average for juveniles for the period).

Dreitz et al. (2004) focused on juvenile survival rates as related to dispersal from natal sites, as well as age post fledging (specifically 30, 60, 90 or 120 days after putting transmitters on nearly-fledged chicks), and relative water levels pre and post movement (actually a water level index, equivalent to a Drought score value, or DSV, see Appendix C). They used the same telemetry data from 1992-1995 reported by Bennetts and Kitchens (1997a). The most parsimonious model for survival included year of study, age of juvenile, and water level (change in water level index pre and post movement). Dreitz et al. (2004) considered the effect of age post fledging to be minimal. Year to year survival estimates (±SE) were 0.73 (±0.04), 0.72 (±0.04) and 0.71 (±0.04) for 1992, 1993, and 1994, respectively. [Survival estimates were likely biased high due to problems with censoring, see Bennetts et al. (1999b), who reported juvenile survival from mark-resight data as 0.52, 0.31, and 0.57 for the same three years]. Dreitz et al. (2004) found a significant positive relationship between survival and dispersal to a wetland with a higher water level index (i.e., kites tended to move out of wetlands with lower than long-term average water levels and into wetlands that at the time had higher than average water levels; see Appendix C for more details on the water level index). No wetlands in the study regions were in drought condition for the three study years, and therefore the significant positive effect of higher water levels on survival was not influenced by extensive dry downs in the natal wetlands. The authors concluded that the model selection procedure yielded “relatively high” uncertainty as to what model best explained the patterns of survival during that period.

Survival and Population Trends: Influence of Periodic Low Water, 2000-Present

Martin et al.'s (2007a) superpopulation estimates included years with periodic drying events in several snail kite federally-designated critical habitats. Martin et al. (2007a) compared population estimates for this period in the context of the USFWS (1999) criteria for removing snail kites from the endangered species list: 1) the 10-year average for the population estimate is greater than 650 birds, 2) the estimate has < 20% Coefficient of Variation (CV) for pooled data, and 3) $\lambda > 1.0$ sustained for 3-year running average. [Note that these criteria were based on population estimates and trends based on the 1969-1994 annual count described earlier]. The authors also compared raw (unadjusted for $\hat{p}$) counts (1998-2005 only) from each of the six occasions within each survey year, focusing on the first count (FC) and maximum count (MC), to validate earlier concerns (Bennetts et al. 1999a) that variation in the counts may reflect detectability rather than environmental conditions.

Following 1997-1999 estimates of ~3,000 snail kites (Dreitz et al. 2002a), Martin et al. (2007a) reported a dramatic decline from 2000-2002, from 2,772 birds down to approximately 1,400 birds (the 95% CI for the 2002 mark-recapture estimate did not overlap those from 2000). From 2002-2005, the population stabilized or increased slightly (all error bars for $\hat{N}$ [estimated population size] from 2002 onward overlap), at approximately 1,100-1,500 snail kites. Based on these observations, they define a pre-decline era (1997-2000), a decline era (2000-2002), and a post-decline era (2002-2005). MCs and FCs (based on raw or unadjusted counts, see previous paragraph) were always below 650 birds from the year 2000 onward. For comparison, Bennetts et al. (1999a) had reported unadjusted counts of 700 to over 900 in 1993-1994, the last two years of the annual fall count. Martin et al. (2007a) compared λ derived from MC, FC, and superpopulation estimates. Clearly, the FC and MC approaches overestimated λ (e.g., 1.57 for $\lambda_{2000/1999}$ based on FC, compared to 0.77 using the superpopulation approach), and the result reinforced the need to estimate $\hat{p}$ (using mark-resighting data and analyses) and adjust the raw counts. The overall $\hat{p}$ averaged approximately 0.3, ranging from 0.25-0.39 for occasion-specific $\hat{p}$ in the 2001-2005 surveys (see supplemental materials referenced in Martin et al. 2007a and available online); these were similar to those reported by Dreitz et al. (2002a) for 1997-2000, but overall greater than those reported for early years of the mark-resighting study (1992-1996, overall average $\hat{p}$ for adults was 0.2; Bennetts et al. 1999b). Based on raw counts, the snail kite population had fallen below the 650 bird minimum recovery target established by USFWS. However, the superpopulation-derived estimates (based on band-resighting) never fell below 1,000 kites from 1997-2005. Population growth rate targets failed to meet the USFWS criteria of

>1.0 from 1998-2002 (3-year running averages were 0.73-0.94); the 3-year running average λ leading up to 2003 population levels (1.05) included the driest year of the period of study (i.e., 2001).

The number of young snail kites recruited into the population declined dramatically after 1998. Martin et al. (2007a) reported a 1992-1998 average of 200 young per year range-wide (a peak of > 300 was reported in 1997), but from 1999-2005, the annual average was 61 young produced. Based on Martin et al. (2007b), the vast majority of young, especially in 1997-1998, were produced in WCA3A (305 of 330 young, 92%, were fledged in 3A in 1997 [Dreitz and Kitchens 1997]). The number of young produced dropped from the 1997-1998 highs to about 50 statewide in 1999, and about 90 in 2000. The number of young fledged in WCA3A in 2000 was 62 (Dreitz 2000). After 2000, the number of young produced in WCA3A per year has not exceeded ~50 (Martin et al. 2007b, Reichert et al. 2011a). One major problem with reporting young produced is lack of detection probability (i.e., what proportion of nests with young were found). For 2005, Martin et al. (2007b) described an unprecedented effort in finding nests, but still only 50 birds were banded. It is clear that statewide, and in WCA3A in particular, many fewer young have been produced since 1999 compared to earlier in the 1990s. They point out that detection probabilities for juveniles were not available in the 1990s and that the timing of the survey (March-June) may miss nests. For example, in 2004, Martin et al. (2007a) reported that birds bred unusually early (p. 478), which resulted in low detection probability of young (0.16, compared to 0.35 in 2005). Bennetts and Kitchens (1997a), reviewing all available data from 1966-1995, reported that 33% of documented nest initiations (i.e., nests with an egg) were in January and February (prior to the March-June survey period).

Nichols et al. (1980), based on annual count data from 1969-1979, estimated a snail kite population "half-life" of 9.5 years; in other words, with poor recruitment but relatively high survival and long lifespan, it would take 9.5 years for the kite population to decline by 50%. Martin et al. (2007a) population estimates indicated a much shorter half-life, roughly a 4-year period (1999-2003) in which the estimated snail kite population dropped from ~3,000 to ~1,500; they concluded that this was the result of poor recruitment in vital habitat areas (Martin et al. 2007a).

Age Dependent Survival

Up through 2000, the oldest confirmed snail kite was 18 years old (Bennetts and Kitchens 1997a), and the bird was still breeding. Reichart et al. (2010), with an additional 10 years of data on birds banded primarily since 1992 (n=2,084 individuals banded), but including some birds

banded prior to 1992 (n=74 observed during the Reichart study), estimated survival rates for birds older than 20 years. They included age specific models, as well as models with the following age classes: 0 up to 1 year, 1-4 yrs, 5-12 yrs, 13+ yrs). Apparent annual survival rates were constant within the four age classes, but differed between classes. Apparent annual survival rates were fairly constant from 1-15 yrs of age (approximately 0.9 ± 0.05 SE), but then declined to approximately 0.4 (±0.2 SE) by age 21 (Figure 5-1). [Age-dependent mortality associated with drought is presented in the next section.]. With the overall decline in recruitment since 2000 (Martin et al. 2007a), it is likely that the snail kite population is increasingly composed of a higher proportion of older birds (Reichert et al. 2011a).

SNAIL KITE MOVEMENTS AND PHILOPATRIC TENDENCIES

En Masse Kite Movements Associated with Regional Droughts

The hydrologic conditions that have received the most attention since the snail kite was listed as endangered are dry downs and/or droughts. Beissinger and Takekawa (1983) reported observations of wetland unit occupancy and movement by snail kites associated with the 1981 drought (see Figure 5-2). Kite sighting information was based on a combination of airboat transects, roost counts, and a "kite hotline," in which kite sighting information was solicited from the public. By this time, "primary use" wetlands had been identified by Sykes (1979, 1983c, and pers. comm., as cited in Beissinger and Takekawa 1983) and included WCA3A, WCA2A/B and LOKEE. "Drought-related" areas (e.g., canals, farm ponds, borrow pits, and others) were those observed to support snail kites only in times of drought. As water levels receded, the number of kites on LOKEE dropped from 214 (December 1980) to 75 (June 1981). Beissinger and Takekawa (1983) stated that 99% of the wetland area of LOKEE was dry July-August 1981. Similar trends were found for WCA3A; whereas 305 kites were counted in December 1980, no kites were found in WCA3A by June. WCA2B kite counts went from 115 in December 1980 down to 12 in March 1981. During this same period of dry conditions and dispersal of snail kites away from these main use areas, kites were found in 46 "drought-related" areas, including a number of urban canals in Palm Beach County, creeks in Volusia County, agricultural canals in Hendry County, and small (2-5 ha) permanent and seasonal marshes throughout peninsular Florida. At the time, LKISS and LTOHO were considered drought-related, and in 1981 they supported up to 35 and 32 kites, respectively, including some nesting kites; this was the first record of kites nesting on these lakes. As water levels recovered in 1982, snail kites returned to

Figure 5-1. Model averaged estimates of annual snail kite survival probabilities (solid line) and estimable annual survival probabilites (•), with standard errors, from the fully age-dependent model (see details in Reichart et al. 2010). Survival data for snail kites 22 years and older were pooled to avoid problems with parameter estimation. Figure from Reichert et al. (2010), used with kind permission from John Wiley and Sons: Oikos, Interactive effects of senescence and natural disturbance on the annual survival probabilities of snail kites, Volume 119, 2010, Pages 972-979, B.E. Reichert, J. Martin, W.L. Kendall, C.E. Cattau, and W.M. Kitchens, Figure 2, © 2009 The Authors. Journal compilation © 2010 Oikos.

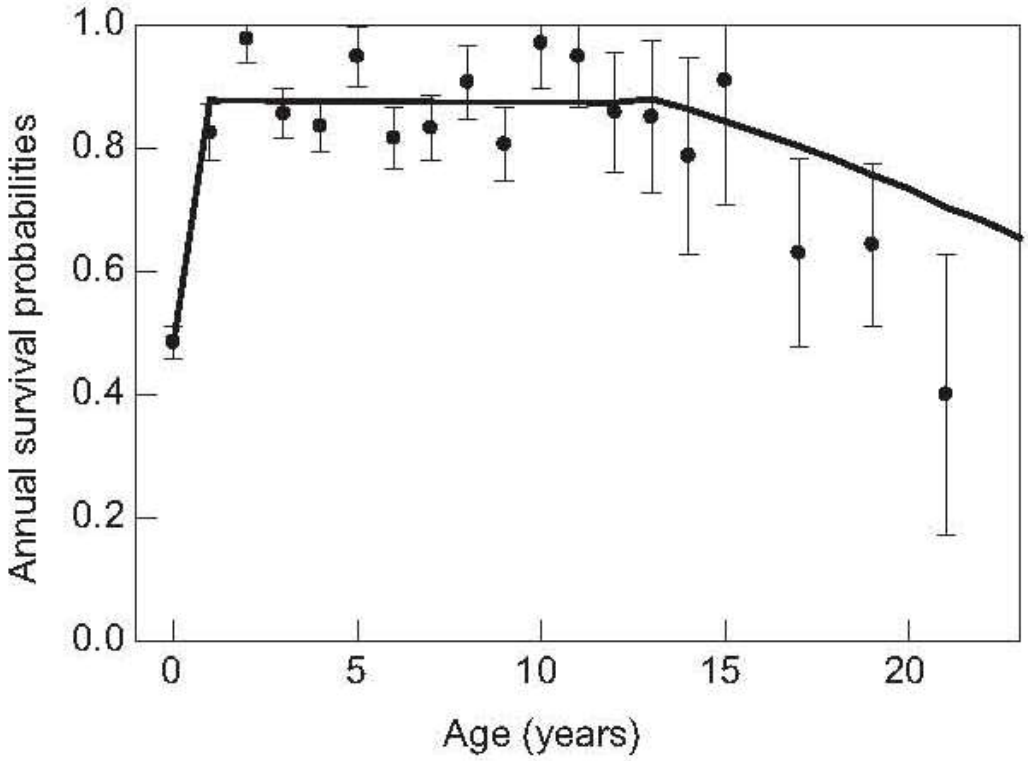
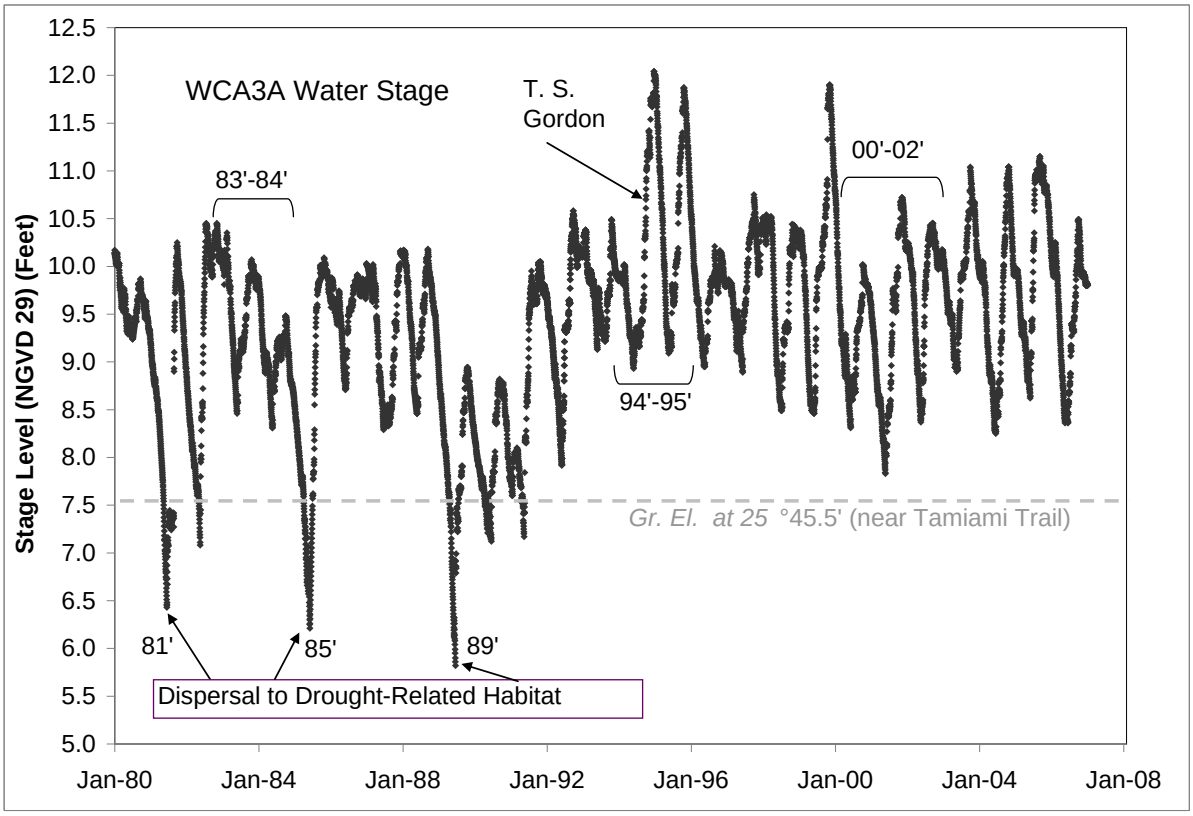


Figure 5-2. Water stage in WCA3A from gauge at Station 3-65 (Site 3A-28) for 1980-2006. Also shown for reference is the ground level just north of Tamiami Trail (St. Rte 41), 7.54 ft above MSL, the lowest ground elevation in WCA3A. Stages at Station 3-65 that are below 7.54 (gray dashed line) mean that all of WCA3A was in dry down condition. Specific reference to 1981, 1985, and 1989 droughts as described in the text. Specific references to 2000-2002 drought period (Martin et al. 2007b, Reichert et al. 2010) and the high water event (1994-1995) initiated by Tropical Storm (T. S.) Gordon (Bennetts et al. 2002) are described in the text.



only one primary use area, WCA3A, which was dry for a shorter period (~4 months in 1981) compared to other primary use areas (Beissinger and Takekawa 1983).

Relatively wet conditions occurred in 1983 and 1984, and snail kite counts reached their pre-1981 (drought) level (~700 kites counted, Rodgers et al. 1988). Another major drought occurred in south Florida in 1985 (Figure 5-2). Water stage dropped sharply from December 1984 to April 1985, again drying out most of WCA3A. Takekawa and Beissinger (1989) again reported "massive dispersal" from primary use areas. As with the 1981 drought, the number of snail kite sightings in drought-related aquatic habitats increased, while those in primary use areas decreased. Twenty-six percent of drought-related locations in 1985 were also used by kites in the 1981 drought. LKISS, as in 1981, received emigrates from drought-impacted wetlands. A few snail kites were observed scattered in drought-related Palm Beach county locations in 1981, but in 1985 the West Palm Beach Water Catchment Area (now called Grassy Waters Preserve [GWP]) was recorded as a kite use area for the first time (13 birds). A roost site adjacent to this catchment area, on Palm Beach County Solid Waste Authority property, supported up to 372 kites at one time (on June 12, 1985; over 50% of the annual count for that year). In 1989, drought conditions returned to the region (see Figure 5-2), and the roost near the Water Catchment Area supported 212 birds (Rumbold and Mihalik 1994). Snail kites roosting in 1989 departed in a westward direction, and were foraging in the Water Catchment Area, as well as canals, ponds and marshes located within approximately 20 km of the roost. This roost has been used nearly continuously since that time, with significant month to month and year to year variation, and an overall average of approximately 30 kites per evening roost count (Marybeth Morrison, Solid Waste Authority of Palm Beach County, unpublished data). Kite counts at this roost periodically exceeded 100, especially when other wetland units in the Everglades (e.g., WCA3A) were experiencing a relatively low water period (e.g., May 2001, June 2004).

Individually Based Quantification of Snail Kite Movements

Prior to 1992, snail kite movements and wetland occupancy were recorded en masse, with limited opportunity to track individual birds. Although these earlier observations accurately portrayed the species as nomadic, and responding to dry conditions by moving to "drought refugia," sufficient data were not available for quantitative analyses. Starting in 1992, a routine annual banding effort was initiated as part of the developing mark-resighting protocol, and Bennetts and Kitchens (1997a) also initiated a 3-year radio telemetry study that focused on movements of ~300 individual kites throughout their range. As stated previously, the mark-resighting protocol has provided data from 1992-present, as well as opportunities to analyze kite

movements under several different hydrologic scenarios (see below). The most intensive survey of snail kite movements ever conducted was the 1992-1995 radio telemetry study conducted by Bennetts and Kitchens (1997a), which happened to coincide with a relatively wet period in general, and a long-term increase in hydroperiod and increased water depths in WCA3A in particular.

General Approaches

From 1992-1994, Bennetts and Kitchens (1997a) placed transmitters on 164 adults and 117 juveniles (young in the nest, just prior to fledging). Individual snail kite locations were found on an approximately biweekly basis via aircraft (primarily) and airboat. Monthly movement probabilities (and in some cases also cumulative movement probability) were estimated from these data from 1992-1995. Bennetts and Kitchens (1997a), Valentine-Darby et al. (1998), Bennetts and Kitchens (2000), Dreitz et al. (2004), Martin et al. (2006a), and Martin et al. (2007c) all used this same 1992-1995 telemetry data, and they analyzed movements at different spatial scales (e.g., wetland to wetland movements vs. region to region) and temporal scales (e.g., month to month, breeding vs. nonbreeding, annual) and using different analytical approaches. The use of multi-state models (where individuals are distinguished by age class, or spatial location [e.g., Everglades vs. LOKEE]) have dominated the analyses in the last several years.

The growing cumulative data from banding birds from 1992-present has provided an opportunity to quantify movements from band-resight data. However, since the banding/ resighting survey occurs only from March-June each year, documented movements reflect only snail kite movements (or occupancy of a wetland) from one March-June period to another March-June period. Monthly (or more frequent) movements between wetlands occur (see telemetry data) in between annual documentation of wetland occupancy by banded birds. Again, multi-state analyses have been applied to the mark-capture data (see Fujiwara and Caswell [2002] for examples of capture histories and a conceptual model of the general approach). Martin et al. (2007c) described multi-state models (citing Doherty et al. 2002) as being statistically more robust than “ad hoc” measures of movement/survival (however, see comments by R. Bennetts in Appendix B).

Since 2007, Ken Meyer (Avian Research and Conservation Institute [ARCI]) conducted snail kite tracking studies using both satellite telemetry and VHF telemetry. Although the primary objective was testing the utility of advanced tracking technologies for collecting snail kite data, some data were obtained on survival, home range, seasonal movements, and detection probabilities (Meyer and Kent 2011). Both a satellite and a VHF transmitter were placed on each

of 10 adult snail kites. Birds were captured in February-March 2007 on LTOHO and LKISS and tracked for three years. Additional satellite transmitters were deployed in 2012; these transmitters have GPS technology which provides much greater accuracy than those used from 2007-2009 (K. Meyer, pers. comm.). Some results of this work are presented below under "Monthly and Seasonal Movements."

Juvenile Dispersal from Natal Wetlands

Bennetts and Kitchens (2000) reported that juveniles with radios dispersed from their natal wetland units with an estimated 0.81 cumulative movement probability. All juveniles dispersed by 240 days post fledging, and 60% dispersed by 60 days. A drought that influenced southern marshes (e.g., WCAs, Loxahatchee Slough, LOKEE) in 1991 may have impacted food availability in 1992, so the authors compared southern movement probabilities to those from northern habitats (KCOL and USJM). Natal departures out of southern wetland units (0.25 cumulative movement probability) were much lower than from northern units (0.90) in 1992. In addition, natal departure was lowest in 1992 compared to 1993-1994 (relatively wet years; Bennetts and Kitchens 2000). This was the opposite of what was predicted based on earlier studies of dry down impacts on apple snails; the expectation was that movement probabilities would be higher in the southern region in 1992, due to the presumed negative effects of dry conditions (most severe in 1989-1990, but continuing into 1991) on apple snails. Instead, juvenile snail kites were much less likely to leave their natal habitats in the southern region in 1992. [It may be that the snail population had not suffered significantly from hydrologic conditions in 1992, since we now know snails have the ability to survive some dry down conditions, see Chapter 6.] By the time southern marshes had remained flooded for two years (1993 and 1994), there was little difference between cumulative movement probabilities out of northern (~0.8) and southern wetland units (~0.85).

Drietz et al. (2004) reported some additional details on movements of juvenile snail kites bearing transmitters, but limited their analyses to kites up to 120 days post fledging. Overall, natal departure rates among all wetlands in the snail kite's range were 14% (1992), 40% (1993) and 45% (1994). Of those that departed, 77% did so within 60 days post fledging. Thirty-five percent moved from one region (e.g., a wetland unit in the Everglades) to another region (e.g., LOKEE or to one of the lakes in the KCOL). In the Everglades region (defined as WCAs, ENP, and Big Cypress, per Bennetts et al. [1999b]) 60% of juveniles departed, with 95% of these juveniles moving to another wetland unit within the Everglades region. They reported more juvenile birds dispersing to wetlands with higher water level indices (indices based on the number

of standard deviations from average monthly means, see Bennetts and Kitchens 1997a); however, actual depth differences cannot be determined by the water level indices (see Appendix C on "droughts").

Monthly and Seasonal Movements

Bennetts and Kitchens (2000) found that water levels were not an important proximate cue for juvenile and adult snail kite movements from one wetland to another during their study in 1992-1995 (but recall that dry conditions did not occur during the study period). The monthly movement probability between individual wetland units was 0.20 for juvenile kites; for adults it was 0.25, but varied between years (0.15, 0.25, and 0.27 for 1992, 1993, and 1994, respectively). Birds that dispersed from a wetland were more likely to move into a wetland that was nearby versus one that was farther away; distance from the original wetland significantly affected in which wetland kites were later found (Bennetts and Kitchens 1997a). Again, the Bennetts and Kitchens data were from a relatively wet era; during relatively severe regional droughts, the distance between abandoned and newly occupied wetlands may increase, resulting in data that reflect longer or more frequent movements (see Takekawa and Beissinger 1989).

Bennetts and Kitchens (2000) also reported capture rates (in snails/minute, based on the time it took a course-hunting bird to capture a snail) for birds foraging in one wetland then moving to another. They found no difference in capture rates pre and post movement, indicating that the movements were not based on food availability, which is a function of snail density and access to the snails (see Chapter 7). They concluded that during this relatively wet era in peninsular Florida wetlands, snail kite movements between wetland units were relatively low risk explorations to find potential foraging opportunities for periods when localized wetlands go dry. They pointed out that wide-spread regional droughts force "massive dispersal" (as stated by Takekawa and Beissinger 1989); otherwise, birds face starvation as snails become unavailable in dry marsh. The Bennetts and Kitchens' 1992-1995 study occurred during wet conditions, so there was no opportunity to document dry down dispersal by birds wearing transmitters.

Bennetts and Kitchens (1997a, p. 78-80) concluded that distance has a negative effect on probability of movement between wetland units. They also found a significant seasonal effect (but also a year*season interaction) for combined juvenile and adult movements (p. 69-70). For example, in 1992, monthly movement probabilities were greatest in summer (~0.3 for both age classes) and lower in spring (0.15-0.25); fewer movements in spring probably reflected January-April nesting activity, which commits snail kites to stay in an area through the breeding cycle (Bennetts and Kitchens 1997a).

Martin et al. (2006a) also considered distance effects on movements between wetland units, and whether movements were influenced by degree of isolation, patch size, and/or some temporal effects (e.g., season), but they used a multi-state modeling approach. They used the same data collected in Bennetts and Kitchens (1997a). They hypothesized that as the landscape becomes more fragmented (increased wetland unit isolation), snail kites would exhibit lower movement probabilities. They predicted that larger wetland areas would attract more kites (i.e., kites would immigrate into larger wetlands more so than smaller wetlands). They also predicted differences between juveniles and adults in their movement responses to fragmentation (degree of isolation) and patch size. Degree of isolation was measured as "matrix," the amount of unsuitable habitat between wetland units, resulting in three categories: 1) contiguous (a group of wetlands with very little matrix and easily crossed physical barriers, like a road), 2) moderately isolated (a group of wetlands separated by < 5 km of matrix), and 3) isolated wetlands (a group separated by > 15 km of matrix). "Matrix" was "generally … nonwetland," agricultural, or urban areas.

The most parsimonious model (lowest Akaike's Information Criterion [AIC] value) was one in which movement probabilities (for adults and juveniles combined) were different by the region (r) in which the bird resided (model weight, scale of 0 to 1.0, was 0.69). Modeling juvenile data only, they found the most parsimonious model (weight=0.79) was one in which monthly movements were influenced by the AR*d effect (AR=area of wetland into which a kite moved, and d =distance between wetlands that a kite moved out of and into). Movement probability decreased with an increase in the distance between two wetland units, consistent with Bennetts and Kitchens (1997a). When the adult-only data were analyzed, only one model (weight 1.0) appeared to explain the data, where region (r) influenced movement probabilities. In a subsequent analysis, within-region monthly movement data (adult and juvenile kites) were best explained by the interaction between season and contiguous wetland (seas*cw); the contiguous wetland (labeled Everglades, or E region) consisted of the WCAs, ENP and BCNP. For this period (1992-1995), monthly movement probabilities between wetland units (e.g., from WCA3A into WCA2B) within E region was 0.29. Overall, monthly movement probabilities among the three categories of isolation were highest among contiguous wetland units (represented by E region), and lowest among isolated wetland units. All of the monthly movement data analyzed in Martin et al. (2006a) and Bennetts and Kitchens (1997a) reflected snail kite movements during a period of relatively high water for all regions (1992-1995; Figure 5-2). This is in contrast to movements documented in 1981 and 1985 that forced kites (i.e., move or starve) out of south Florida when the majority of the Everglades reached dry down conditions (see "En Masse Movements" above).

Meyer and Kent (2011) found that most individual snail kite movements were 20-40 km in distance, but some were 115-220 km long. The mean total distance that the 10 transmittered kites moved over the study period (2 years) was 1,898 km. When snail kites moved, they remained in their new locations for 1 day to over 3 months. The authors also found that the sites used by kites included small wetlands within habitat generally considered unsuitable and/or outside of areas included in the annual snail kite monitoring protocol; kites may stay in these areas for extended periods of time.

Monthly Movements Associated with Regions

Bennetts and Kitchens (1997a) identified a set of regions throughout the snail kite's range in order to distinguish between a series of contiguous impounded units in south Florida from lakes and isolated marshes as follows: 1) Everglades and Big Cypress Region (WCAs 1,2,3; ENP; BCNP), 2) Loxahatchee Slough (GWP [formerly the West Palm Beach Water Catchment Area], Pal-Mar Water Control District, Corbett Wildlife Management Area, and private wetlands), 3) LOKEE, 4) KCOL (LKISS, LTOHO, East LTOHO, Marian, Jackson and others), 5) Upper St. Johns (BCWMA and all wetlands in Upper St. Johns Basin), and 6) Peripheral region (agricultural ponds and other wetlands not in the other five regions).

Martin et al. (2006a), based on 1992-1995 telemetry data, described movements between these regions. Martin et al. (2006a) estimated monthly movement probability from the Everglades region to another region (to LOKEE or to KCOL) at 0.04, as compared to 0.29 between units within the Everglades region. Monthly movement probabilities from region KCOL to other regions was 0.09 (as compared to 0.15 between lakes within KCOL). These less frequent regional movements (which require greater distances traveled) were consistent with an overall negative distance effect described above. Again, these 1992-1995 telemetry-based estimates were not influenced by dry down events. Bennetts and Kitchens (2000) reported that monthly movement probabilities *within regions* (wetland unit to wetland unit) were higher in wetter years; the lowest movement probability was in 1992 within the Everglades region (~0.12), but it increased to ~0.25 in 1993 and 1994. [Martin et al. 2006a had reported 0.29. See hydrologic conditions for this period, Figure 5-2].

Between-Year Movements

Martin et al. (2006a) used band-resight data (birds banded from 1992-2003) to assess changes in wetland occupancy by individuals on an annual basis. South Florida wetlands were subject to drought conditions in 2001. Martin et al. (2006a) based relative drought scores on the

long-term average water level from 1992-2003 (see Appendix C). Based on Martin et al. (2006a), 2001 was a drought year for LOKEE, the WCAs and SJM, but not for LTOHO and LKISS. In general, 2000-2002 were relatively dry years compared to the 1993-1997 high water period (see Figure 5-2). However, dry years in the 1992-2003 period were not nearly as dry as when "massive dispersal" events had been noted for snail kites, for example in 1985 (Figure 5-2; Takekawa and Beissinger 1989).

Martin et al. (2006a) used multi-state models to distinguish annual movement probabilities between juveniles (30-365 days old) and adults (>1 year old) and among different regions (see above for regional designations). The authors analyzed movement probabilities for adults and juveniles as affected by 2000-2002 relatively dry conditions (D_{1-2}) and lowest water level year only (2001, as D_1), as well as regional effects (r) and time (t), and a suite of comparisons between specific regions. The most parsimonious model (with weight=0.96) was one in which annual movement probability was explained only by the interaction of $r*D_1$. For all years except 2001, movement probabilities were constant. For 2001, movement probabilities were highest from the LOKEE region to the KCOL region (0.33). In non-drought years, movement probabilities from LOKEE to the KCOL region were 0.04. Annual movement probabilities from the Everglades region to other regions were not statistically significant between relative drought (2001) and non-drought years.

Martin et al. (2007c) estimated annual movement probabilities between regions for snail kites banded from 1992-2004. As in earlier multi-state models, they distinguished between adult and juvenile movements and between regions. Martin et al. (2007c) defined 2000-2002 as a drought period (2001 being the driest year) and compared movements for this drought period to those pre- and post-drought. They looked at movement probability as a function of age, drought, natal region, and region (i.e., movement from a region that was not their natal region). To evaluate a drought effect on movements, they compared only 2000 (non-drought year) to 2001 (see Figure 5-2 and Appendix C to compare hydrologic conditions in these two years). The most parsimonious model included movement probabilities from natal region (N) to post-dispersal region (O) that differed from 1) movements from O to N, and 2) movements from O to other non-natal regions, labeled A. Movement probabilities (ON vs. NO vs. OA) depended on the natal region (Everglades region vs. LOKEE, etc.). Annual movement probabilities from N to O were lowest for the Everglades region, and <0.1 for all regions. Annual movements from O to N were significantly higher, ranging from approximately 0.2 to 0.5. A drought effect (comparing movements in a 2001 drought to 2000 non-drought) was not included in any of the models selected as explaining the movement data (Martin et al. 2007c). Martin et al. (2006a) found a

2001 drought effect, as part of an $r*D_1$ interaction (see above). Martin et al. (2007c) concluded that the lack of a drought-related movement effect may reflect a small sample size (i.e., 2000 vs. 2001 years had few kite movements on which to base their analyses; sample sizes were not reported). [In our assessment, it may also reflect a relatively small difference in hydrologic conditions as compared to other severe drought years, see Figure 5-2]. Note that 2001, although considered a drought in this analysis, was not nearly as dry as 1981 and 1985, when snail kites left the Everglades region (see Appendix C).

Philopatry

Martin et al. (2007c) estimated movement probabilities between regions and discussed natal philopatry (the probability that a snail kite fledged in a particular region will be found in that same region the next year). The probability of occupying a region between March 1-May 30 from one year to the next (regional philopatry) ranged from ~0.98 (Everglades region) to 0.72 (Kissimmee lakes region). [See the first paragraph under "Monthly Movements Associated with Regions," above, for a list of the wetland units within regions]. Bennetts and Kitchens (1997a) showed probabilities of finding snail kites in their natal wetland based on *wetland unit*, and they reported much lower numbers for natal philopatry. For example, the probability of finding a snail kite in its natal wetland was 0.45 for WCA3A and 0.6 for WCA2B (Bennetts and Kitchens 1997a), compared to 0.98 for the combined WCAs and other wetland units in the region designated as Everglades (Martin et al. 2007c). Martin et al. (2007c) concluded that natal philopatry, as has been shown in studies of other species, may be a way to reduce risk associated with movements. However, snail kites frequently move between wetland units on a month to month basis (less so between regions), and the movement probabilities Martin et al. (2007c) reported were based on annual surveys. Martin et al. (2006a) analyzed movements between regions (the same regions described by Bennetts and Kitchens 1997a), and shed light on issues of habitat fragmentation for kites.

Driving Forces for Population Change and Changes in Survival Rates

In the last 30 years of publications on snail kites, the nearly exclusive environmental parameter used to explain temporal and spatial variation in kite survival and abundance has been water stage. No analyses reflect a direct measure of food availability, although water levels can directly affect food availability (e.g., kites have no access to snails in dry down conditions). Water levels can also affect apple snail abundance; dry downs can decrease snail survival, depending on duration, as well as snail recruitment, depending on timing. Relatively high water

also appears to negatively impact apple snail recruitment and needs to be considered as we attempt to relate snail kite demographics to water stage. Here we provide a summary of publications/reports on the responses of snail kite population size and/or survival rates to water stages.

Assessment of Snail Kite Population Response to Hydrology Based on Kite Count Data (1969-1989)

Beissinger (1995) examined the effects of periodic environmental fluctuations on the population viability of the snail kite by modeling different environmental states. His analyses were based on the annual snail kite count data collected from 1969-1989. [The environmental state method is fully described in Beissinger (1995); environmental states represent discrete sets of environmental conditions thought to affect kite demography]. A preliminary assessment based on stochastic population fluctuations indicated that nesting success, as well as changes in population size between consecutive years and the length of the breeding season, were positively related to water level and rainfall. The model output indicated that conditions of low water lead to snail kite dispersal and low recruitment, increases in adult mortality, and declines in the population. [Note that the data analyzed (kite counts from 1969-1989) included years with much more severe drying events than described above for movements reported between 1992-2004.] Stage-based life tables for three different environmental states (drought, lag years post-drought, and high water years) were used to study the effects of cyclic drought. Model results indicated that snail kite populations would increase when drought intervals were greater than 3.3 years, with even more rapid growth when the interval between droughts was over 4.3 years. The author noted some shortcomings of this modeling approach to snail kite demography. First, little data existed on survivorship at the time, and the model used was sensitive to estimates of this variable (Beissinger 1995). Second, the model was not spatially explicit, thereby not accommodating the possibility of kite emigration and immigration between wetland units that could influence their survival and nest success (i.e., if they can avoid a dry down and find alternative flooded wetlands with snails). Another limitation that emerged later, following analyses by Bennetts et al. (1999a), was that the Beissinger 1995 model was based on demographic metrics derived from the annual kite counts. Although that was the best available information at the time, there were problems with using the counts for such a purpose (see Sykes et al. 1995, Bennetts et al. 1999a, and previous discussions in this report).

Beissinger (1995) suggested that a lack ("lack" due to water management regimes moving towards more frequent drying) of long hydroperiod marshes would probably lead to a

decline in the apple snail population and the species that prey on them. In contrast, Darby et al. (2008) found snails quite tolerant to drying events lasting 1-2 months; also, habitats associated with long hydroperiod marsh (e.g., *Nymphaea* slough with few emergent species) supported significantly fewer snails (Karunaratne et al. 2006). Beissinger (1995) stated that the Everglades is one of the least seasonal wetlands in the Neotropics (i.e., that water depths do not fluctuate nearly as much in the Everglades as in other wetlands). This may be true, but water depth fluctuations, including periodic drying events, are critical to supporting Everglades flora and fauna (DeAngelis and White 1994, Sklar et al. 2002). What characterizes least or most seasonal, and what constitutes a moderate or severe drought is a matter of degree. Beissinger (1995) concluded that "increased seasonality of water levels (i.e., greater water level fluctuations, presumably increasing dry down frequency) could be expected to have negative effects on other components of the ecosystem." [For additional discussion of what constitutes a drought or dry down, see Appendix C]. The magnitude of fluctuations that influences snail kites, apple snails, and their habitats were not well understood at the time, and work published later by Bennetts, Kitchens, and colleagues on kites, and Darby and colleagues on snails, illustrate the need for fluctuations, including periodic drying events, that benefit snails and kites. Bennetts et al. (1998a) discussed, at length, problems with management recommendations for kites that focused on increasing the interval between droughts and stabilizing water levels. The authors stated that such management recommendations overly simplify the system and, if carried out, lead to adverse effects to snail kite habitats in the long term (e.g., loss of wet prairie, see Zweig and Kitchens 2008). They also pointed out that studies assessing drought effects have not addressed the spatial extent or severity of a given drought, even though these factors probably greatly influence effects on snail kite survival and reproduction (Bennetts and Kitchens 1997a, 1997b).

Snail Kite Population Response to Hydrology (1992-present)

Following the 1989-1990 drought, the next several years were relatively wet throughout the snail kite's range (see Bennetts and Kitchens 1997a). From 1992-1997, the number of nests fluctuated somewhat, but the Everglades region consistently accounted for the majority of the nests statewide (Bennetts et al 2002). Bennetts et al. (2002) found the fewest successful nests (36) in the Everglades region in 1992 (one year after prolonged dry down conditions), and the highest numbers (135 and 192) in relatively wet years (1995 and 1997, respectively; also see Table 3-1, but note that some variation in nest numbers from year to year may be due to varying levels of effort to find nests [R. Bennetts, pers. comm. [and see R. Bennetts Comment Matrix, Comment #11, Appendix B.]). Despite large differences in nest numbers, WCA3A alone

consistently supported ~52% of successful kite nests range-wide (47 to 56%). Bennetts et al. (2002) reported that juvenile $\hat{S}$ (apparent survival) increased during a 1994-1995 high water event (HWE), but the HWE had no influence on adult $\hat{S}$. However, Bennetts et al. (2002) found that during their period of study, there was more annual variation in survival for juveniles than could be explained by the HWE alone. Bennetts et al. (2002) suggested the HWE may have helped juveniles by flooding a greater portion of the wetland landscape (e.g., BCNP in addition to WCAs) compared to non-HWE years. Juveniles tend to disperse from natal habitats within 90 days of fledging (Bennetts and Kitchens 2000), so as the inexperienced birds dispersed in 1995 they were more likely to encounter flooded wetlands that could support foraging. This would not be the case in more typical hydrologic years, where dispersed birds would be much more likely to encounter dry marsh (e.g., if they flew from WCA3A in the direction of Big Cypress). More details on the influence of the 1995 HWE on snail kite nesting is presented in the next section.

Relatively high water conditions continued in WCA3A and other regional wetlands in 1998-1999, and concern was expressed regarding habitat degradation in WCA3A due to prolonged inundation and high water (see Bennetts et al. 2002). As the mark-resighting study continued beyond 1999, hydrologic conditions changed such that the potential impacts of low water on survival and other demographic metrics could be analyzed. The relatively high water conditions (especially in WCA3A) from 1993-1999 were followed by a 2000 summer-fall with lower than average precipitation and widespread low water conditions in marshes throughout south Florida. For example, the graminoid marshes of LOKEE were dry for longer than one year starting in May 2000 (Steinman et al. 2002, Darby et al. 2008).

Martin et al. (2008) considered the potential impacts of habitat degradation resulting from high water in the 1990s, as well as the added impact of a 2001 drought year, on the snail kite population. They provided estimates for population growth rates during these hydrologic phases, and also used life table response experiments (similar to Beissinger 1995, but using kite banding data from 1992-2005) to simulate kite response to a range of hydrologic conditions. They tested hypotheses as to why there had been no recovery of the snail kite population since 2001: 1) long-term habitat degradation due to high water from 1992-1999; 2) moderate drying events in March-June 1999-2005 that limited kite recovery (this same period included record high water levels in Fall 1999, and high water in 2003); and 3) long-term degradation due to high water, followed by short-term droughts. They considered these analyses as “exploratory,” not analyses that can demonstrate specific conditions that impacted the snail kite population. Because the Martin et al. (2008) analyses were considered exploratory, and effectively raised questions about possible mechanisms that have yet to be analyzed, we will focus here on key findings (and critical

assumptions) that address the main hypotheses listed above. The methods and derivation of model parameters and model sensitivity analyses were extensive (four pages, plus five separate appendices), and will only briefly be explained here.

Martin et al. (2008) assessed the relative contributions of $\hat{S}$ (annual survival) and recruitment on λ (population growth rate), including a sensitivity analysis of parameters such as juvenile detection probabilities. They looked at differences in the relatively wet period (1992-1999) versus the relatively dry period (1999-2005, which includes the > 50% decline in the snail kite population). They considered "wet" years as 1993-1998, 2003, and 2005, based on deviation from average long-term water levels based on stage data from 1992-2005 (citing Martin [2007] for definitions of wet). Martin et al. (2008) identified 1999, 2000, 2002, and 2004 as "moderately dry," and 1992 and 2001 as "drought" years (see contrast to Bennetts and Kitchens 1997a, p. 109, and more discussion in Appendix C].

Martin et al. (2008) reported demographic metrics based on banding data and the superpopulation approach (see Dreitz et al. 2002a). Estimates were made for survival of adults (Pa), juveniles (Pj), and subadults (Ps, kites 1-2 years of age). Fecundity (m) was estimated for adults (m_a) and subadults (m_s). Fecundity was defined as the number of young females produced per reproductive female (also see Nichols et al. 1980). Detection probabilities (β) for juveniles were needed to estimate fecundity, but empirical data were only available for 2004-2005 (0.16 and 0.35, respectively). For all other years, they assigned β values of 0.16-0.35 as most reasonable based on sensitivity analyses of the matrix population model. Martin et al. (2008) also looked at λ, population growth rate, based on estimates of successive year $\hat{N}$, to evaluate the three hypotheses. They modeled λ as a function of low-frequency moderate drying (1 moderate drought in 7 years) versus high frequency moderate drying (4 in 7 years). Moderate drought years reflected conditions observed in 1999, 2000, 2002 and 2004. More severe drought years were 1992 and 2001.

Sensitivity analyses indicated that λ was most sensitive to adult survival and adult fertility (F_a). F_a is a function of juvenile first year survival and those juveniles surviving to adults with fecundity m_a; F_a=Pj*m_a. Fecundity (m_s) of subadults had a negligible effect on λ. They concluded that m_a (adult fecundity) had a greater impact than Pj (juvenile survival) on λ. They found λ decreased from 0.94 to 0.85 when β was set at 0.16 up to 0.7. Regardless of β, the greatest influence on λ was F_a . When they increased moderate drought frequency in their model, λ decreased from 1.13 for the 1992-1998 period, down to 0.92 for 1999-2005. A decrease in adult fertility contributed the most to the decline in λ between the two periods in the model.

Adult fertility tends to vary more than $\hat{S}$ (see Martin et al. 2007a) and likely influences λ on a more frequent basis.

Martin et al. (2008) concluded that both habitat degradation (due to long-term inundation in the 1990s) and drying events (that occurred in 2000-2005) have contributed to the suppressed snail kite recovery observed since 2002. Although exploratory in nature, Martin et al. (2008) provided some conservation implications. The authors concluded that managers should reduce the frequency of moderate drying events in managed wetlands used by snail kites. They noted that this contradicts Bennetts (1998, dissertation), where Bennetts concluded that moderate drying events did not appear critical to kites (also see Bennetts et al. 1998a).

Cattau et al. (2008, Appendix A) analyzed stage data from the gauge at Station and Site CA3AVG, which represents average stage for gauges at Stations 3-63 [Site 3A-3], 3-64 [Site 3A-4] and 3-65 [Site 3A-28] in WCA3A (i.e., CA3AVG is not an actual gauge, but an average of data from the three mentioned gauges; gauge locations shown on Figure 2-1), in order to relate hydrologic conditions from 1992-2008 to juvenile snail kite survival and nest success. Among a suite of eight hydrologic metrics analyzed, two, REC (recession rate, starting from January 1 until the minimum stage for the year was reached) and MIN (minimum stage), had a statistically significant effect on nest success. As REC increased and MIN decreased, nest success decreased (P=0.009 and P=0.049, respectively, for the logistic regression). Greater nest success was associated with water depths >10 cm (estimated from stage data) compared to years in which depths fell below 10 cm (P=0.056). Estimates for the 10-cm depth threshold were based on measured depths and well data as presented in Zweig and Kitchens (2008). Cattau et al. (2008) concluded that MIN had the strongest negative effect on nest success *when depths fell below 10 cm*. The effect of REC may be associated with low water years where terrestrial predators gained access to nests and/or foraging opportunities were constrained due to low water.

Cattau et al. (2008) found that amplitude, the difference between the maximum stage that occurred October 1 through December 31 and the MIN stage (which typically occurs during the kite breeding season), influenced juvenile survival. The most parsimonious model included an amplitude effect separated by the periods 1992-1998 and post 1998. For the period 1992-1998, there was no influence of amplitude (an average of ≈ 1 foot NGVD) on juvenile survival (which averaged ≈ 0.5). However, for 1999-2008, juvenile survival fell to ≈ 0.1 as amplitude increased to approximately 3.0 feet. Survival rates 0.5 and higher were associated with annual minimum stages (CA3 AVG gauge) of 9.3 and above. As described by the authors, the amplitude effect may be a function of relatively high water stages that encourage snail kites to establish nests at relatively high ground elevations (see Bennetts et al. 2002, described earlier). Then,

during years with relatively high amplitudes, water levels recede to a MIN such that the nests become exposed to dry conditions— left "high and dry" per Cattau et al. (2008). The median amplitude for 1992-1998 was significantly lower than that for 1999-2008, which explains the significant negative relationship within the latter period but not within the former.

Finally, with regard to hydrologic impacts on snail kite demography, Reichert et al. (2010) found an age-dependent sensitivity to the relatively dry conditions in 2000-2002. They found that adults >13 years of age suffered higher mortality than adults 1-12 years old in drought years (2000-2002). The 1-12-year-old adults' $\hat{S}$ declined from a non-drought average of ~0.95 down to ~0.65 during the 2000-2002 drought, while >13-year-old birds' $\hat{S}$ dropped from ~0.9 down to ~0.35 (Figure 5-1).

Work by Meyer and Kent (2011) provides an example of how data collection protocols can influence study results and conclusions, as pointed out in Chapter 2. Survival was estimated for adult snail kites bearing both VHF and satellite transmitters. Separate estimates were made from the VHF data, which requires periodic ground or flight surveys in a designated survey area to pick up radio signals, and from the satellite data, which obtains data on a daily basis regardless of kite location. For the 10 birds in 2007, the VHF telemetry data yielded a survival rate of 67%, while the satellite-based estimate was 100%. Survival was also found to be 100% in 2008 using satellite transmitters (the VHF transmitters had expired by the end of 2007). The 67% estimate from 2007 was likely influenced by failure to pick up signals from just a few birds out of the 10 total. Also, it should be noted that 2007 was a relatively dry year (see Cattau et al. 2008). The fact that kites tend to disperse to "drought-related" habitats when major wetlands go dry (described earlier in this chapter) may have affected the detection of some of the VHF-transmittered birds. Based on our review of the Meyer and Kent (2011) study, regional drying events that influence survey areas, including those involving aerial surveys to pick up VHF signals, may influence efforts to estimate snail kite survival and other demographic metrics.

NESTING

Chapter 3 provided information on the nesting substrates most often used by snail kites and how the substrate types vary by region and/or wetland type, as well as typical water depths recorded under nests in Florida. Here we focus on nest success/failure as influenced by hydrology and nest substrate. Management activities undertaken to enhance nest success or avoid impacts to snail kite nests are also discussed in this section. We describe the hydrologic needs of some common nesting substrates in Appendix D. Also note that the annual snail kite nest

monitoring that has been conducted consistently since the 1990s through the present is described in Chapter 2.

Nest Success, Numbers and Distribution: General Description

Until recently (see below) there have been no direct studies of the specific causes of nest failure, and determining cause is difficult due to lack of evidence (Bennetts et al. 1994). However, various authors have reported causes of nesting failure, including the structural collapse of nests, predation, and nest abandonment (Bennetts et al. 1994). As described in Chapter 3, nests built in woody substrates are less likely to collapse and therefore generally more successful. No differences in nest success were found among nests in willow, pond apple, cypress, or punk-tree in the Everglades (Bennetts et al. 1988). Bennetts et al. (1988) also found no clear connection between nest height and success.

Upon examining the loss of 11 nests (~83%) in LNWR (WCA1) in 1970, Sykes (1987a) reported that the predation rate was inversely correlated with the distance of the nests from upland habitats. He also concluded that snail kite nests need to be > ~200 m from uplands (including dikes and levees) to avoid upland predation sources. In contrast, Bennetts et al. (1988) compared nesting success among nests falling into three categories of distance to upland habitats (i.e., <100, 100-500, and >500 m). For the first year of the study, they found that nests in the 100-500 m category had significantly lower success than nests in the > 500 m category. Analyses of the second year's data indicated no significant differences between categories. Differing conclusions between the two studies may have to do with the many differences between WCA1 and WCA3A, including hydrologic gradients, position of canals, and abundance and distribution of tree islands (e.g., see Brandt et al. 2000). Predation concerns were also raised for snail kites nesting in BCWMA due to its relatively small size and compartmentalized nature (with levees separating compartments; Martin et al. 2005b).

During the 2010 snail kite nesting season, the UF snail kite monitoring team used game cameras to study the causes of snail kite nest failure (Olbert 2011). They monitored 41 nests (many of which were successful), primarily on LTOHO. Their cameras captured the causes of failed nests at about 24 nests; predation, especially by snakes, accounted for more than half of the nest failures.

There has been disagreement in the snail kite literature concerning nest abandonment and what constitutes a breeding attempt (Bennetts et al. 1994). Disagreement and inconsistency concerning the definition of breeding attempt carries forward into estimates of nest success and nest abandonment. For example, Bennetts et al. 2002 (and all of Bennetts' work) defined a

successful nest per Steenhof and Kochert (1982) as at least one young reaching 80% of the average age of first flight (i.e., 24 days post hatch for a snail kite; Bennetts et al. 1988). Similarly, Snyder et al. (1989a) considered a nest successful if any of the young reached banding age (mid to late in development). However, Snyder et al. (1989a) considered a **breeding attempt** to start with nest building, while Bennetts et al. (all of Bennetts' work) considered a breeding attempt to begin with the laying of the first egg. Bennetts et al. (1994) and Bennetts and Kitchens (1997a) explained in detail the reasons for using the latter definition of breeding attempt. These reasons include that nest building is part of courtship in the snail kite, and more than one male may court (initiate a nest) with a single female. Bennetts et al. (1994, p. 513) provides a discussion of **nest abandonment**. Snyder et al. (1989a) suggested that nest abandonment was a frequent cause of nesting failure, but, at least during favorable water conditions, Bennetts et al. (1994) showed that this was not the case when nests without eggs were excluded from the analysis. Over a 5-yr period (1979-1983), Beissinger and Snyder (1987) reported only five cases of nests abandoned with eggs (four cases) or young (one case); Sykes (1987c) reported four cases of nest abandonment with eggs or young over a 10-yr period (1968-1978); and Bennetts et al. (1988) observed only two nests abandoned (out of 375) in 1986-1987 during favorable water conditions (Bennetts et al. 1994). Bennetts et al. (1994) state, however, that nest abandonment of eggs or young may be a more important cause of nest failure during drought periods when food is limited.

Reports of annual nest success vary greatly among studies, wetlands, and years, even when consistent definitions are used. For example, over eight years of monitoring in the BCWMA (1991-1998), annual nest success ranged from 11% in 1998 to 56% in 1992 (various authors, as cited in Dreitz et al. 1999). Two reports (Bennetts and Kitchens 1997a and Dreitz et al. 2001) summarized findings from multiple studies of nest success for 1968-1995 and 1972-1997, respectively, for the WCAs, LOKEE, LKISS, LTOHO, and SJM and other areas. Average annual nest success (excluding nests with no eggs and those placed in artificial nest supports) ranged from 29-58% (see Bennetts and Kitchens 1997a, p. 55 for details). The success range for some studies included 0%, especially when researchers included nests found in the nest building stage.

Snail kite nesting studies have focused on water levels and their effects on reproduction. As described in Bennetts et al. (1994), there has been general agreement that kite reproductive effort and success are reduced during drought years. For example, Beissinger and Snyder (1987) reported that there was no successful nesting in WCA3A or WCA2A in 1981-1982 due to

drought. The dry conditions in these years led to snail kites dispersing to other areas; the first records of breeding on LTOHO and LKISS were in 1982 (Beissinger and Takekawa 1983).

Other than dry marsh conditions, the influence of water depths on snail kite nesting appears less conclusive, and there have been differences in the conclusions reached by different investigators (Bennetts et al. 1994). Some concluded that kite reproductive success was influenced greatly by water levels (Sykes 1983c, Beissinger 1986), while others found scant evidence for such an effect (Sykes 1987a, Bennetts et al. 1988, Bennetts and Kitchens 1996a). Bennetts and Kitchens (1996a) found that nest success was not influenced by water depths *at the nest sites*, and they suggested that as long as a certain (threshold) amount of water is present at the nest site, then it probably is not an important factor in determining success (Bennetts et al. 1994). Studies by Sykes (1983c) and Beissinger (1986) included years with drier conditions, and perhaps water levels in some cases were below such a minimum threshold. Lack of a water depth effect in other studies may have reflected relatively high water stages during their periods of study (e.g., in WCA3A in 1986-1987 as reported in Bennetts et al. [1988] and 1993-1995 as reported in Bennetts and Kitchens [1996a]). Nesting success was significantly different in low and high water years in one study (Snyder et al. 1989a), but the authors believed this was partially explained by differential use of nesting substrates between the years (e.g., in drier conditions, little water remains under willow, so kites nest in herbaceous plants which are more prone to collapse). Bennetts et al. (1994) caution that their own results were for the Everglades and the situation may be different in lake habitats, where water levels may affect the selection of nest sites and predator access to nests.

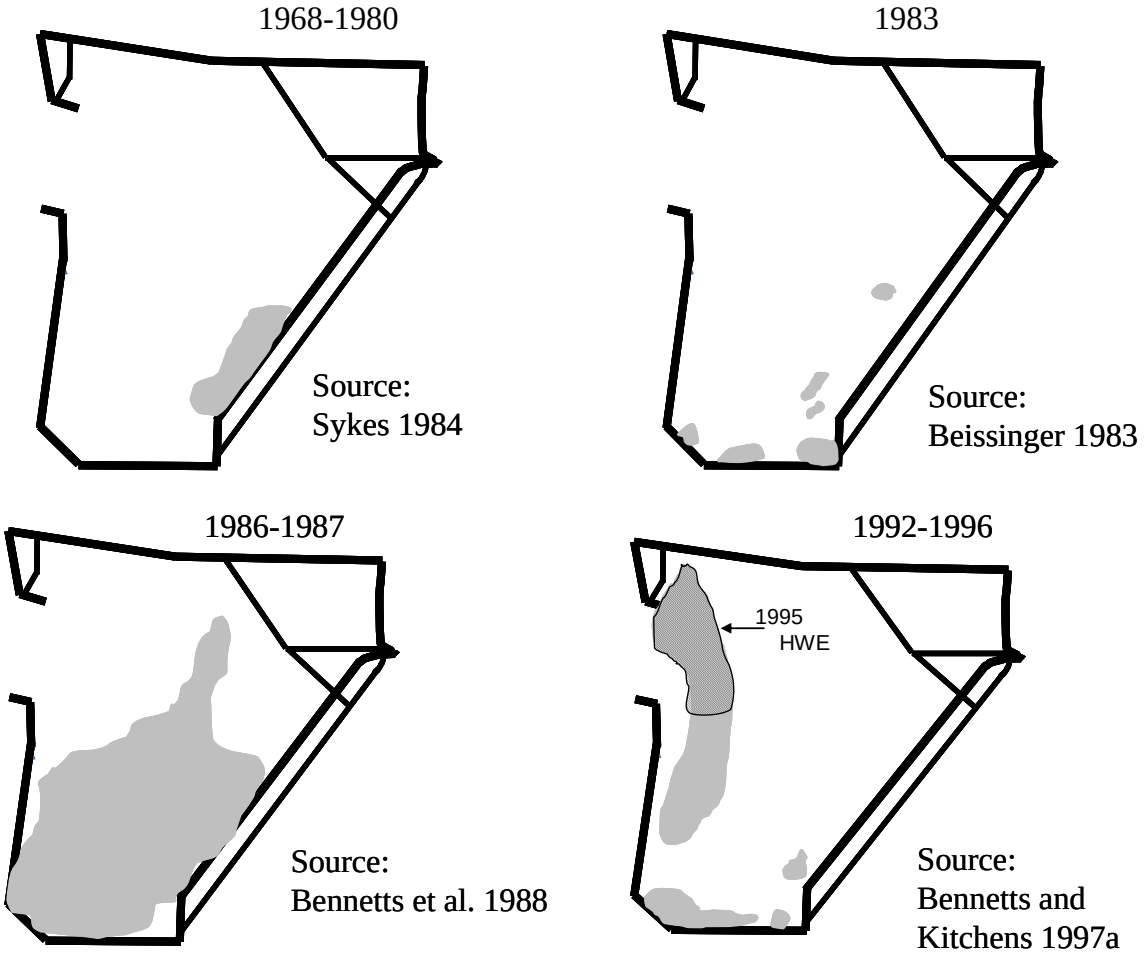
Nest Success, Numbers and Distribution Associated with Hydrologic Conditions: Emphasis on WCA3A

The majority of spatially explicit snail kite nesting data comes from WCA3A, reflecting the fact that during range-wide nest surveys, the majority of nests were found in WCA3A (Table 3-1). In addition, the first detailed study of kite nesting ecology was conducted in WCA3A in 1986 and 1987 (Bennetts et al. 1988). Bennetts et al. (1988) found 148 kite nests and 65 young fledged in 1986, and 227 nests and 172 young fledged in 1987. Most of the snail kite nesting activity in these two years was in WCA3A, although use of WCA2B was also relatively high (Bennetts et al. 1994). Water levels in 1986-1987 were higher than the long-term average during the primary nesting season (Figure 5-2). In both years, snail kite nests were distributed in WCA3A (south of I-75; Figure 5-3) within a relatively narrow range of ground elevations (Bennetts et al. 1988). Nearly all of the nests (94%) were initiated in sites with water depths

between 20 and 80 cm (Bennetts et al. 1988). Note that large portions of WCA3A south of I-75 experienced dry down conditions in 1985, the year before 148 kite nests were found (Figure 5-2). Bennetts et al. (1988) estimated that these 1986-1987 nesting areas went dry, on average, once every 1.9 to 3.8 years over a 19-year period of record. Bennetts et al. (1988) reported that snail kites do not appear to nest in the WCAs in areas that dry down ***less*** frequently than about once every 4 years (see Chapter 9 for a discussion of different reports of appropriate dry down return intervals that influence kites).

In October 1994, tropical storm Gordon impacted south Florida and resulted in record high water stages in WCA3A (Figure 5-2). Water levels in the Everglades soon exceeded 3 and 4 standard deviations above the 30-year averages (Bennetts et al. 2002). The high water event (HWE) did not appear to affect snail kite nest success or the number of young per successful nest, but it led to a significant shift in the distribution of nesting kites (Bennetts et al. 2002). In the January-June 1995 kite breeding season, the kites tended to nest and forage at higher ground elevations in WCA3A (26° 57' and further north), compared to previous years when birds nested in more southern parts of the WCA (vicinity of 25° 50'; Figure 5-3). Snail kites nesting at 26°, and further north, foraged there (R. Bennetts, pers. comm.). Based on ground level estimates from Bennetts et al. (1988), EDEN (2010), and Darby and Wight (2011), ground levels 26° and further north are ~35 cm higher than in southern WCA3A. For the few nests established during the HWE in southern (deeper water) WCA3A, Bennetts et al. (2002) noted that the birds were foraging in ENP or the "Pocket" (area between WCA3A and WCA3B), which had shallower water. Bennetts et al. (2002) noted that emergent wet prairie grasses and sedges were entirely submerged in the high water event, possibly reducing the number of snails surfacing to breathe air. Most areas south of 26° in WCA3A had water depths greater than 1 m (and many, greater than 1.5 m); these water depths were greater than those previously known to be used by kites (e.g., Bennetts et al. 1988, Sykes et al. 1995) and may have been too deep for effective foraging. In the 1996 nesting season, with lower water levels, the distribution of nesting snail kites generally shifted back to the southern portions of WCA3A (Bennetts et al. 2002) (Figure 5-3). A similar pattern of switching to higher elevations to nest and forage also occurred in WCA2B during the 1995 HWE (Bennetts and Kitchens 2002). Kites also moved into BCNP to nest during the HWE, an area typically too dry to support foraging and nesting kites. Rodgers (1992) reported a similar shift in nest locations on LOKEE; in low water years kites nested at lower ground elevations (near the littoral zone/open water interface), but with higher water conditions

Figure 5-3. The distribution of snail kite nests (gray shading) in WCA3A from 1968-1996, reflecting relatively low water stages (1968-1980, 1983) and relatively high water stages (1986-1987, 1992-1996). Nest distribution during the 1995 high water event (HWE) is indicated (horizontal stripes). Map shows the WCA3A northern boundary at I-75 (Alligator Alley) and the southern boundary at State Route 41 (Tamiami Trail). Sources as cited in Bennetts et al. (1998a). Adapted from Figure 3 in Bennetts et al. (1998a), used with kind permission from the Wildlife Management Institute, Inc.: Trans. 63rd No. Am. Wildl. and Natur. Resour. Conf. (1998), Recovery of the snail kite in Florida: Beyond a reductionist paradigm, Volume 63, 1998, Pages 486-501, R.E. Bennetts, W.M. Kitchens, and D.L. DeAngelis, Figure 3.



kites shifted nesting activities to higher ground elevations of the southwestern LOKEE littoral zone. The idea that high water may affect snail kite use of a wetland had been alluded to earlier; Sykes (1983b) commented that some areas were flooded "too deeply and too long" to support snail kites, but this was based on a largely qualitative assessment.

Snail kite use of WCA3A remained high throughout the 1993-1998 period, and at least 305 kites fledged from 168 nests in WCA3A in 1997 (Dreitz et al. 2000, see Table 3-1); nest success was estimated at 0.51. We found no data on young produced in 1998, but there were at least 178 active nests, and nest success dropped to 0.31 (Dreitz et al. 2000). The number of nests and nest success declined further in 1999 and 2000 (Dreitz 2000, Dreitz et al. 2000). This may be attributable to habitat degradation, as described by Martin et al (2008) and discussed in a previous section.

From 2000 to the present, there have never been more than ~80 active snail kite nests reported in WCA3A, and nest success has been ≤ 0.40 (Cattau et al. 2007 and Martin et al. 2002a, 2002b, 2003, 2005a, 2006b, and 2007b provided nest success estimates for this period; also see Table 3-1 for numbers of nests). Depths were sufficiently low in 2001 such that no kite nests were detected. From 2002-2004, nest success was 0.34-0.4 with ~60-80 nests detected. In 2005, a relatively high water year in WCA3A (Figure 5-3), there were only 12 known active nests and all were unsuccessful (Martin et al. 2007b); this was the first time on record that all active nests in WCA3A failed. The number of active nests was again small in 2007 and 2010, and they too all failed. There were no known active nests recorded in WCA3A in 2008. Although low water conditions might explain why no nests were detected in 2001, it is clear that the few nests and nest success rates of zero cannot always be attributed to low water; 2005 and 2010 were relatively high water years, but there were few nests and they were unsuccessful. In 2005, Darby et al. (2009) reported adult-sized apple snail densities < 0.14 / m^2 in five of six sites monitored at the time (see Chapter 7 for references to estimated minimum threshold snail densities for kites). The National Research Council (2010) concluded that the current regulation schedule in WCA3A has contributed to the kite's recent decline, because it exaggerates seasonal changes in water levels. Water levels too high and too low (in different seasons) can result, and these extreme conditions can affect kite nest success, juvenile survival, the duration during which kites can breed, apple snail recruitment, and snail densities (Mooij et al. 2002, Martin et al. 2008, Cattau et al. 2008, Darby et al. 2009).

Meta-Analysis of Snail Kite Nest Success and Perspectives on Scale and Interpretation

Meta-analysis is a statistical approach wherein data sets from multiple independent studies (and often different researchers) are analyzed to draw general conclusions from a collective body of research (Gurevitch and Hedges 2001). Dreitz et al. (2001) studied spatial and temporal variability in nest success throughout the snail kite's entire range in Florida using meta-analysis. One of the factors they examined was the effect of hydrology on nest success (using annual minimum water levels). They conducted a meta-analysis using data from six independent studies covering 22 years (1972-1997 [except 1984-1985 and 1988-1989, years for which there were no data]) and 11 wetlands. They tested for the effects of area, year, habitat type (lake or marsh), and water levels on annual nest success using logistic regression. A low water event was defined as a period of time when water level was ≥ 1 standard deviation below the mean (the authors did not explicitly state the periods for the stage data they used, but said they followed Bennetts and Kitchens 1997a, which used data from every year starting in 1969, as available). They found considerable variability in nest success over time and space, but the variation was greater than could be explained by water levels alone (Dreitz et al. 2001, 2002b). They did not find that water levels were good predictors of annual nest success. Dreitz et al. (2001) stressed that their results do not suggest that low water levels do not influence nest success (as nearly all nests failed during low water events), but that the number of nests affected by low water conditions in their study was very low (18 of 1541, or 1%). They suggested that the following factors would lead to the effects of reduced nest success during low water events being relatively minor: 1) low water events occur about once every 5-10 yrs (Duever et al. 1994); 2) such events rarely encompass the entire kite range (Bennetts and Kitchens 1997a and 1997b); and 3) snail kites are capable of moving to other areas to nest (e.g., Bennetts and Kitchens 1997a).

Beissinger and Snyder (2002) disagreed with some of the main conclusions of Dreitz et al. (2001) and other aspects of the study (such as the model used to analyze the data). In examining points of contention with the Dreitz et al. publication, Beissinger and Snyder (2002) reported that few snail kites nest and fledge young under low water conditions (although they did not define "low water conditions"); low water may cause kites to skip attempts at nesting, shorten the breeding season, and/or decrease the possibility of nesting more than once in a season (Beissinger and Snyder 2002; also see Sykes 1979, Beissinger 1986, Snyder et al. 1989a). However, some areas of disagreement originate in the different definitions of breeding attempt / nesting attempt and nest success described earlier. Beissinger and Snyder disagreed with Dreitz et al.'s (2001) definition of a nesting attempt excluding nests found during the prelaying period (the reasoning for which was also described earlier [see Chapter 3 under "Nesting Season, Clutch

Size, and Young Produced"]). Dreitz et al. (2002b) provided a response to Beissinger and Snyder (2002), and in so doing further elaborated on the findings and points in the Beissinger and Snyder commentary. Dreitz et al. (2001, 2002b) reiterated that nest success can be substantially reduced during low water events, but they disagreed with Beissinger and Snyder over "the explanatory power of water level effects on nest success over broader scales. When considered in a broad context, using a meta-analysis, the explanatory power of water levels is weak" (Dreitz et al. 2002b). Also in their response, they presented the results of a new analysis on the frequency and extent of low water events over a 33-year period (1965-1997) in 13 wetlands. They found that for each year, low water events were most frequently localized, or in < 10% of the 13 wetlands. Low water events affected more than 50% of the wetlands in only 4 of the 33 years, and a low water event encompassed > 60% of the wetlands in only one year in 33.

The overall conclusion we draw from these papers is that although low water conditions in a particular area in a particular year may lead to no or few snail kites nesting there, overall, these *localized* (i.e., individual wetland unit) conditions have less influence on the kite population as a whole; kites move to other wetland units with sufficient water and snails in order to nest (Beissinger and Takekawa 1983, Takekawa and Beissinger 1989, Dreitz et al. 2002b). However, several years of poor conditions, as indicated by Martin et al. (2008) for habitat degradation in WCA3A, may be much more problematic for snail kites in the long run. Based on apple snail data from several wetlands deemed critical to kites, Darby and colleagues have pointed out that although alternate wetlands may have enough water to attract snail kites, many wetlands in the kite's range, including WCA3A, have fewer apple snails now than in the past (Darby et al. 2004, Darby 2006, Darby et al. 2009, Darby et al. 2012). When a relatively rare regional drought occurs, snail kites have fewer or few options, so overall we would expect reproduction (ultimately measured by the number of young produced) to be significantly reduced, and stressed kites may experience higher mortality rates (Sykes 1979, Beissinger and Takekawa 1983, Bennetts et al. 1994, Martin et al. 2006a). This is also consistent with the conclusions from the exploratory analysis of Martin et al. (2008) (see above description of that study).

Management Activities to Improve Snail Kite Nesting

Although successful nesting obviously depends on the availability of suitable nest substrates, we found no reports of suitable nest substrates being a limiting factor for snail kite nesting in a wetland unit, nor did we find reports of changes in the quantity of nest substrates (e.g., abundance of pond apple trees, acreage of willow stands) causing changes in snail kite nest numbers or success. Most woody substrates require periodic low water or dry down conditions to

persist. The hydrologic conditions thought to support some of the woody and herbaceous substrates used by snail kites are described in Appendix D.

The fact that snail kites tend to nest in cattail or bulrush on lakes more so than in the Everglades (Sykes et al. 1995), and that nests may fail at higher rates when constructed in herbaceous plants (see Chapter 3), may be an indication that woody substrates are limited on the lakes. However, snail kites frequently used herbaceous nest substrates when the kite population was increasing or stable in the 1980s-1990s, per Bennetts et al. (1999a); relatively low reproductive output in the 2000s has not been associated with a reduced availability of woody (or other) nest substrates. Without data on shifts in availability, as well as depths associated with available habitat, any cause and effect relationship with kite nesting cannot be made. For example, on LKISS, Rodgers and Schwikert (2001) reported that there was a shift away from nesting in woody substrates to herbaceous substrates after the managed drawdown in 1995-1996, but concluded that "a direct relationship between snail numbers, habitat quality, and kite productivity has not been demonstrated."

An area where nest substrates available in the 1990s were intentionally eliminated was in WCA2B. A substantial number of snail kites used WCA2B for nesting in 1994 (72 active nests), 1995 (181 active nests), and 1998 (102 active nests); 75% of nests were established in punk-tree (*Melaleuca*) in 1995 (Dreitz and Kitchens 1996). Control of exotic punk-tree began in 1996, with the few nests occurring in that year in cattail and willow (Dreitz and Kitchens 1996). Since that period, punk-tree has been eliminated from WCA2B, and measures to prevent its re-establishment continue to be taken (Rodgers et al. 2011). It is possible that preferred nest substrate is now limited in WCA2B, although data on the availability of other types of nesting substrate are not readily available. From 2000-2010, no nests were found in WCA2B in seven of those years, and the total number of nests from the other four years combined was 48. However, snail densities in WCA2B in 2006 were also found to be quite low (0.03, 0.087, and 0.167 snails/m^2, per Darby et al. 2009), and this may explain (at least partially) the drastic reduction in kite use of WCA2B since 2000.

Artificial Nest Supports

Snail kite nests in herbaceous vegetation (compared to woody substrates) are more prone to collapse or being blown down by wind or rain (e.g., Sykes and Changler 1974, Snyder et al. 1989a, Sykes et al. 1995). To address this problem, Sykes and Chandler (1974) experimented with artificial nest structures or supports in the early 1970s. In the spring of 1973 on LOKEE, four artificial nest structures were used to support nests that appeared likely to collapse or be

blown down. The artificial structures, made of metal, are described in detail in Sykes and Chandler (1974). The structures were successful in terms of birds accepting them (after their nests had been placed in them). Of the four nests, two were successful and fledged five young; the other two nests failed because of predation on the eggs. The authors noted that modifications to the artificial structures might reduce predation.

In their experience with supporting nests (n=94) in the 1970s and early 1980s, Snyder et al. (1989a) saw a 47% success rate (considered successful when at least 1 young reached banding age) of 74 nests (found during the egg stage) that had been transferred from cattail into baskets. Rodgers (1998) had similar success with nests he stabilized on East LTOHO, LTOHO, LKISS, and LOKEE from 1987-1993. Twenty snail kite nests that were likely to collapse were stabilized. All of the nests contained either eggs or nestlings, and they were placed in baskets similar to those used by Sykes and Chandler (1974) or on inflated plastic rings (when they had settled close to the water). Most of the nests (17 of 20) were in either cattail (14 of the nests) or bulrush (*Scirpus validus* [now *Schoenoplectus tabernaemontani*]). Nine of the 20 nests (45%) successfully fledged young, while the remaining nests that were stabilized were either abandoned or collapsed. This level of success was comparable to an overall success rate of 45.5% (for all unaltered/unstabilized nests monitored [n = 876 nests] during the entire study. Rodgers (1988) found that nest collapse accounted for nearly 20% of nest failures. Snyder et al. (1989a) reported that the majority (64%) of 152 nest failures of identifiable cause in cattails was due to probable/possible nest collapse, while only 16% of 107 nest failures of identifiable cause in willows were due to nest collapse. Note, however, that the authors included the nests they had manipulated (in cattail) as nest failures, because they were found "tipping over and in imminent danger of collapse." Note also that their categories of nests included some found during the nest building stage. Rodgers (1998) pointed out that nest support may be particularly effective during drought conditions when nests are most likely to collapse. Drawbacks to an artificial nest program, however, included the cost and effort involved.

Creating Buffer Zones to Protect Snail Kite Nests during Exotic Plant Control

As described above, snail kite nests in herbaceous vegetation are more susceptible to collapse due to settling, wind or rain, or low water levels. In the late 1990's multiple government agencies in Florida instituted a program to avoid disturbance to kite nests after observing the loss of several nests on LOKEE following herbicide applications (Rodgers et al. 2001). Herbicide applications (of 2,4-dichlorophenoxy acetic acid [2,4-D] and 6,7-dihydrodipyrido pyrazinediium dibromide [diquat]) to kill water hyacinth and water lettuce (which often raft and settle around

emergent lake vegetation) also incidentally killed cattail and bulrush that supported the nests. The FFWCC made recommendations to delay herbicide applications in the next year until after the snail kite nesting season, or to institute buffer zones between treated areas and nests in herbaceous vegetation. The approach included the use of a buffer zone of 75 yards (68 m; and up to 100 yards if necessary) around the perimeter of nesting colonies, and 25-50 yards (23-46 m) around single nests (see Rodgers et al. 2001 for additional details). The pilot effort was successful, with none of the 19 nests on LOKEE in 1988 being adversely impacted by control efforts. The program was expanded to include other areas in the Kissimmee Valley in the next year, and no nests (of 1,074) were known to be lost from herbicide applications during 1989-1993.

FORAGING

Factors Influencing Snail Kite Foraging

Research on snail kite foraging has examined snail-hydrology-habitat relationships (Takekawa and Beissinger 1989, Karunaratne et al. 2006, Darby et al. 2008), targeted prey sizes (Sykes 1987b), preferred foraging habitat types (Sykes et al. 1995, Bennetts et al. 2006), and seasonal climatic conditions that influence snail kite foraging efficiency (Cary 1985, Stevens et al. 2002). The availability of apple snails to foraging snail kites is a function of "kite-sized" snail densities and environmental factors that affect their availability. [Based on Sykes 1987b, we consider snails > 20 mm shell width to be "kite-sized," i.e., large enough for kites to eat]. The vast majority of kite foraging reports and publications available to date did not include estimates of apple snail density. In this section we address the environmental conditions that influence apple snail availability, with the assumption that snail densities were sufficient to support snail kite foraging. The critical role that snail density plays in kite foraging will be addressed in Chapter 7. The most influential documented environmental factors on apple snail availability to foraging snail kites include temperature, wind, vegetation type and stem density, and water depth (Beissinger 1983, Cary 1985, Bennetts et al. 2006). Here we focus on vegetation and water depth effects, as well as other less well known effects, that are potentially influenced by management. Temperature and wind effects on foraging were discussed in Chapter 3.

Vegetation

For successful foraging, snail kites must see snails at or near the water's surface; vegetation (or any other structure) that reduces visibility of the water's surface would negatively impact foraging. The type and density of vegetation varies greatly across the kite's range and

among habitat types routinely encountered, and it has been suggested that the structure of habitat (e.g., emergent plant density, proportion of water surface obstructed) has a greater influence on kite foraging than the particular assemblage of plant species (Bennetts et al 2006). Snail kites do not forage over dense habitats like dense sawgrass or cattail marsh, or where floating vegetation (e.g., water hyacinth or water lettuce) blankets the surface (Sykes 1987b). [Agricultural runoff has stimulated the growth of many plants, creating denser vegetation and reducing the kite's available foraging habitat (Sykes 1987b)]. Beissinger (1983) and Bourne (1985a) also reported snail kites avoiding dense vegetation for foraging. Bennetts et al. (1988) described suitable foraging habitat in a portion of WCA3A as approximately 30-40% open water mixed with emergent vegetation, but the estimate may not be an appropriate generalization (see R. Bennetts Comment Matrix, Comment #15, Appendix B). Approximately 97% of foraging bouts observed by Sykes (1987b) were over wetland habitats with relatively open water and scattered emergent or floating vegetation. In the Everglades, three of the most common distinct types of habitat are sawgrass patches, wet prairie, and slough (see Loveless 1959). Wet prairie habitat is a mix of open water and scattered emergent stems of varying densities and species, with *Eleocharis cellulosa* and *Panicum hemitomon* some of the most common species associated with kite foraging (Bennetts et al. 2006). Slough habitat is dominated by open water and lily pads, most commonly *Nymphaea* (Gunderson 1994, Stober et al. 2001, Givnish et al. 2008).

Bennetts et al. (2006) quantified the influence of emergent vegetation density on snail kite foraging in *Eleocharis*- and *Panicum*- dominated wet prairies in the Everglades. Vegetation structure was considered sparse (stem densities < 30 per 0.5 m^2) or dense (exceeding 60 stems per 0.5 m^2 in some cases; also see Karunaratne et al. 2006), and they measured visual obstruction using a Robel pole. The researchers also quantified the amount of available wet prairie and other habitat. Results indicated that the different structural types were not used for foraging by kites in proportion to their availability; 69% of the total study area was sparse habitat and 31% was dense habitat, but 94% of prey captures were in sparse habitat. Snail kites were observed passing over dense vegetation and focusing their search for snails in relatively sparse habitats. This suggested that habitat structure was more influential on foraging habitat selection than snail density (given that snail densities exceeded 0.3/m^2 in the two study sites), and that snail kites would avoid foraging in habitats with greater visual obstruction of the water's surface even if they had higher snail densities than found in the sparse (and/or lower visual obstruction) habitats (Bennetts et al 2006). Note that because of the growth habit of *Panicum*, visual obstruction of the water's surface was greater than with *Eleocharis* at similar stem densities. These "dense" vegetation patches visually obstructed the water surface by 80 to nearly 100%.

Effects of vegetation density on kite foraging have also been observed for snail kites in other areas. In a study of snail kites in Guyana, South America, Beissenger (1983) reported that kites abandoned rice fields during peak rice production due to increased vegetation growth and the inability to detect snails at the water's surface. At the same time, another avian species, the limpkin, which hunted by probing, continued to hunt even with the taller, larger vegetation.

Darby (2006) reported snail kite snail captures and available vegetation types in littoral zone habitats of LKISS. Kites captured 68% of their prey in the shallow littoral zone (depths generally <40 cm), which was dominated by torpedo grass (*Panicum repens*) and alligator weed (*Alternanthera philoxeroides*); kites showed a statistically significant preference for foraging there relative to deeper water habitats. Despite pickerelweed supporting nearly twice the number of snails (per m^2) as alligator weed and torpedo grass, snail kites did not target pickerelweed for foraging. This may reflect reduced visibility of the water surface caused by emergent plant structures (not measured by Darby 2006, but see Bennetts et al. 2006). Alternatively, or in addition, alligator weed and torpedo grass tend to occur at shallower depths than pickerelweed (although depth ranges overlap; Darby 2006), and kites may have had greater access to snails in the shallower water (see Sykes et al. 1995). Open water patches (with no emergent stems) were avoided based on their availability (i.e., there were fewer captures of snails than expected based on the availability of open water). Snail kites captured apple snails in Egyptian paspalidium (*Paspalidium geminatum),* but they did so in proportion to the plant's relative availability (Darby 2006). This plant, which occurs in the outer edge of the littoral zone, may become more important if the inner littoral zone becomes dry, rendering snails unavailable there; during the 2005 study, however, only a small portion of the shallow littoral zone became dry (Darby 2006). Snail kites showed a preference for foraging in low stem density bulrush (*Scirpus validus* [now *Schoenoplectus tabernaemontani*]), <14 stems per 0.5 m^2), which may also reflect a concentration of snails (as bulrush is targeted by snails for oviposition). Appendix D contains information on the hydrology of vegetative communities used by snail kites for foraging.

Harassment from other Avian Species

Boat-tailed grackles (*Quiscalus major*) have been known to harass and attempt to steal apple snails from snail kites, but none were observed to be successful in doing so (n >20; Sykes 1987b). When harassed in flight, kites maneuvered away from the harassers; when harassed on a perch, they moved to another perch (Sykes 1987b), thereby increasing snail handling time. Red-winged black birds also harass snail kites (P. Darby, UWF, pers. obs.), possibly as a response to a perceived predation threat from a raptor. Darby (unpublished data) found that a successful snail

kite foraging bout lasted 80 seconds in the absence of harassment. When the same kites were foraging in the same location on the same day but being harassed by black birds, the foraging bout exceeded 200 seconds. Darby (unpublished observations) found grackles and blackbirds harassing kites much more frequently on lake habitats, possibly reflecting closer proximity to urban/suburban environments (in contrast to interior WCA3A, for example).

Water Depth

As mentioned in this document, snail kites require inundated wetlands to forage for apple snails. From observations of approximately 2,000 kite foraging bouts from 1967-1980, Sykes (1979) reported that kites foraged in waters with depths ranging from 0.2 to 1.3 m. Based on their observation, Kitchens et al. (2002) reported that snail kites typically abandon foraging areas when depths fall below 10 cm. [Interestingly, this is also the water depth below which snails generally stop moving (Darby et al. 2002)]. In areas with higher concentrations of flocculent material (e.g., benthic periphyton, floating periphyton, and other plant materials) receding waters concentrate the material, and even at depths of ~20 cm this material may nearly saturate the water column to a consistency of oatmeal, rendering snails unavailable (P. Darby, UWF, pers. obs.). In addition to very shallow water, snail kites also appear to avoid relatively deep water (e.g., > 1.3 m) for foraging (Sykes 1979) and nesting (e.g., > 1.15 m [Sykes 1987a, Bennetts et al. 1994]). Avoidance of deeper water may reflect direct negative impacts on the availability of apple snails (e.g., when emergent plants become submerged, as suggested by Bennetts et al. 1988). Longer-term effects of deep water include shifts in habitat structure (e.g., wet prairie to *Nymphaea*-dominated slough) that result in lower snail density (Karunaratne et al. 2006). Caution should be taken if/when using nest locations as a reflection of local foraging conditions. For example, in WCA3A in 1992-1996, snail kites nesting in southeastern WCA3A foraged in shallower-water wetlands outside of the WCA (i.e., ENP and the "Pocket" between L-67A and L-67C levees; Bennetts et al. 2002). Darby (UWF, pers. obs.) observed snail kites nesting in WCA3B in 2010 fly east out of the wetland unit, and later saw kites foraging in wetlands bordering State Route 997 (Krome Avenue, Miami).

Some of the greatest concentrations of foraging snail kites ever reported were in WCA3A in depths of 10-20 cm in 1994, in the vicinity of N 25° 58' / W 80° 48' and in sites further north and west (see Figure 8-1 in Chapter 8). Bennetts and Drietz (1997) observed up to 54 snail kites in a foraging patch. The kites were foraging among mixed flocks that included egrets and ibises. The authors concluded that the wading birds acted as "beaters," possibly driving apple snails to surface more frequently and thus become more vulnerable to kites. Bennetts and Drietz (1997)

found other sites in the vicinity that were dominated by limpkins, up to 116 in a site, indicating that apple snails were in great abundance in the area at the time.

CHAPTER 6: APPLE SNAIL DEMOGRAPHY AND RELATIONSHIPS TO HYDROLOGY AND VEGETATION

INTRODUCTION

This chapter addresses patterns of Florida apple snail abundance (measured primarily as density) and distribution, and it focuses on how they are influenced by hydrology and vegetation. Apple snail movements, egg production, survival, and water chemistry/contaminants are major topics of this chapter, as they ultimately affect snail abundance and distribution.

Both apple snails and snail kites respond to hydrology and aspects of plant community composition. Although they share some similarities in their responses (e.g. snails and kites do not reproduce in marshes under dry down conditions), they also benefit from different habitat conditions (e.g., snail recruitment benefits from relatively lower water levels). Compared to snail kites, reports of apple snail demographics and response to habitat condition have been relatively recent and fewer in number. As with snail kites, drought conditions have received the most attention among a range of hydrologic conditions (see further discussions that follow in this chapter), but high water events (increased depth) have also been shown to negatively impact apple snail populations (e.g., Darby et al. 2005). Much of what we perceive about snails has been interpreted through kite response, which has led to conclusions about snails (e.g., their lack of dry down tolerance) that have proven to be incorrect (Darby et al. 2008). Managing for conditions to facilitate apple snail population recovery to a level that supports snail kite foraging and nesting (e.g., in WCA3A, which currently supports very low apple snail densities) may require multiple years of targeting hydrologic conditions deemed unsuitable for kites (especially for nesting, which requires months of suitable local foraging conditions). Here we summarize the available information on wetland habitat conditions influencing apple snail abundance.

APPLE SNAIL MOVEMENTS AND WATER DEPTH EFFECTS

Darby et al. (2002) used radio transmitters on apple snails to monitor movements at approximately weekly intervals during two seasons, spring and winter. The spring study was conducted in marsh habitat at BCWMA, where they found that snails moved, on average, 14.0 ± 1.4 (SE) m per week, and up to 83 m per week. The winter study was conducted at LKISS and found that snails moved, on average, 7.8 ± 1.5 (SE) m per week, and up to 42 m per week. Movement rates (distances traveled per week) were not affected by water depth or temperature (Darby et al. 2002), but

the tendency to move was affected by water depth. Water temperature affects snail activity (Stevens et al. 2002), and likely movements, but temperatures during the Darby et al. (2002) study fluctuated little at each location. Apple snails tended to stop moving when water depths fell below 10 cm. The greatest tendency to move along a positive depth gradient (from shallower to deeper water) occurred when snails were in water 10-20 cm deep. However, snails that made these movements along a positive depth gradient still eventually became stranded. For example, of 31 snails monitored on LKISS, only one moved to deeper water and escaped the drying event. Darby et al. (2002) suggested that as the areal extent of a dry down increases, the number of snails stranded likely increases proportionally. Snails tended to move towards shallower water when water depths were ≥ 50 cm, suggesting a preference for water < 50 cm (but not so shallow as to impede movement). They concluded snails were unable to find deep water refugia when faced with a dry down. The reason that snails stopped moving once water levels receded to 10 cm was unclear, but the authors considered two possibilities. The first was that a concentration of vegetation and suspended material in the shallow water caused an impediment to movement, and the second was that ceasing movement was a behavioral response in preparation for aestivation during an ensuing dry down (Darby et al. 2002). No work has been done on the potential effects of recession rates on movements. It is plausible that more rapid recession of water would result in more apple snails being stranded.

DIRECT AND INDIRECT EFFECTS OF WATER DEPTH ON APPLE SNAIL SURVIVAL

As touched on in Chapter 4, recent research has focused on apple snail survival during dry down conditions and as affected by various aquatic predators. This section will expand on those findings and present information on other factors affecting apple snail survival relevant to water level management. No studies have addressed the potential direct effects of deep water on snail survival; survival studies have emphasized dry down impacts.

Direct Effects of Dry Down Conditions

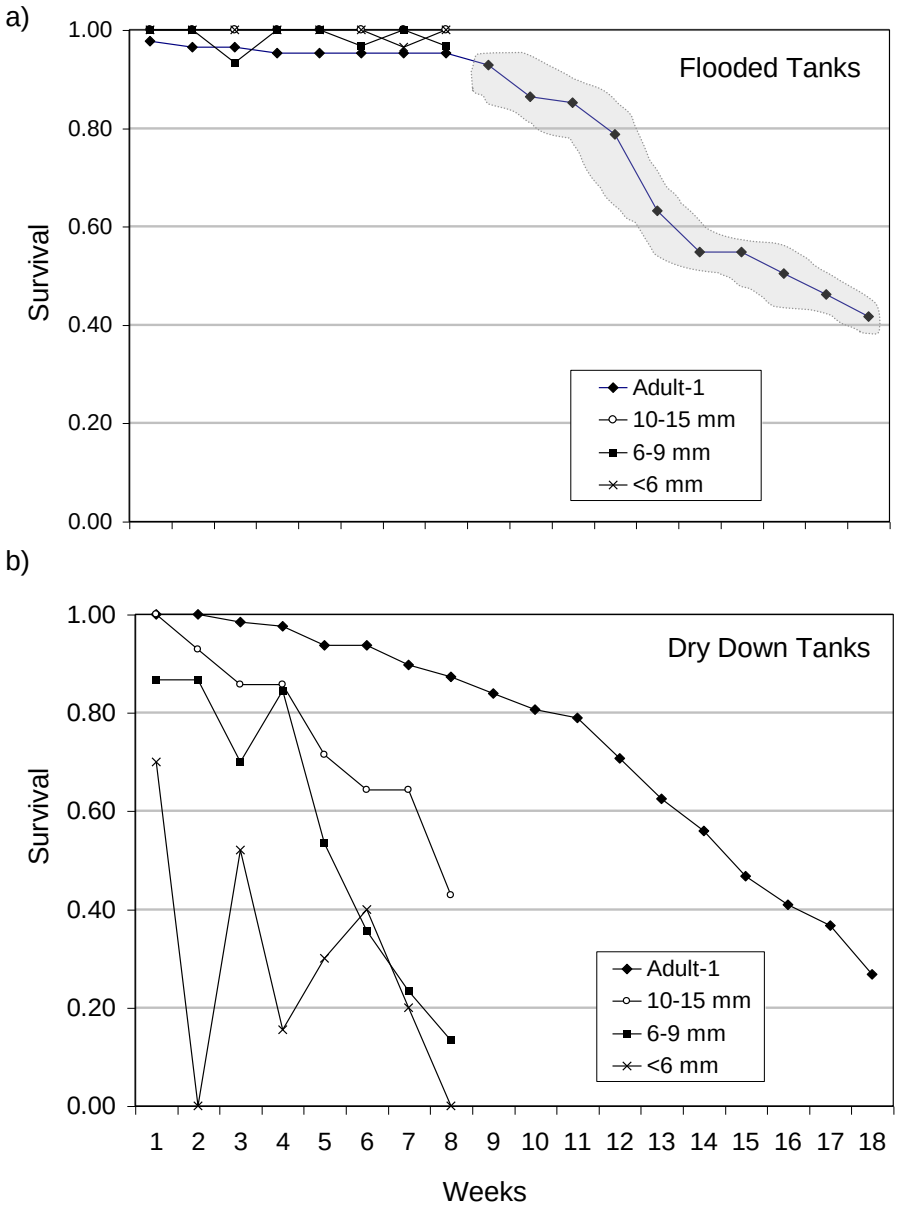
Kushlan (1975) monitored apple snail abundance in the Everglades and related changes in snail abundance and snail sizes to water depths. During this time (1966-1972), their study sites in ENP were frequently subject to dry down conditions. The snail densities (based on use of a 4.5-m^2 Higer pull up trap) were < 0.1 snails/m^2 for most of the study period, but increased to 0.4 snails/m^2 after 2 years of flooded conditions. Densities dropped from 0.4 (1970) down to < 0.1 snails/m^2 after a year with dry down conditions. Average snail size tended to increase after a drying event. Kushlan

(1975) concluded that dry downs reduce snail survival, and that juvenile snails have a lower dry down tolerance compared to adults (evident by fewer juveniles after a dry down year). No direct observations on snail survival were made. He noted, however, that some adults must survive, as egg clusters appeared shortly after marshes were flooded following a dry down. The idea that apple snails have limited dry down tolerance prevailed for the next 20 years (see review in Darby et al. 2008).

Early reports of no or little dry down tolerance in Florida apple snails were likely confounded by an annual adult die-off (see Chapter 4). Darby et al. (2008) accounted for the annual die-off in their laboratory study of the Florida apple snail's ability to survive dry downs. They created mesocosms with sand substrates that could be drained (treatment tanks) or flooded with standing water (controls). Darby et al. (2008) showed that an individual's ability to survive dry down conditions depends on its size and reproductive status. Three laboratory experiments were conducted using adult-size snails (~30 mm shell width) prior to, during the peak, and at the end of the reproductive season (Darby et al. 2008). Pre-reproductive adults were adult snails, approximately 9-12- months-old, that had over-wintered, as well as adult-sized snails that had hatched in the same calendar year (approximately 4-6 months old). These snails had not yet expended energy on reproduction. The researchers found that these pre-reproductive adult snails survived dry marsh conditions for several weeks to months (94% survived 6 weeks of dry down conditions, 71% survived for 12 weeks; Figure 6-1). Juvenile snails in dry down conditions had lower survival rates than pre-reproductive adults, and survival depended on size (Darby et al. 2008). At least 70% of the 6-9-mm (1-2-week-old) and 10-15-mm (3-4-week-old) snails survived after 4 weeks in dry down conditions, while survival for 3-5 mm-snails (newly hatched) was more erratic and between 0 and 50% after 4 weeks. Survival of all juvenile snails fell below 50% after 8 weeks in dry down conditions (Figure 6-1).

Darby et al. (2008) analyzed wetland dry down patterns from 1985-2004, and they concluded that the majority of apple snail populations in wetlands critical to snail kites (LOKEE, WCA3A, WCA2B, among others) would survive the dry downs that occurred during this period. The exceptions were: 1) a managed dry down, combined with drought conditions, which caused the LOKEE littoral zone to be dry for more than 12 months in 2000-2001; and 2) another drying event that lasted for more than 12 months in 1988-1990. The average dry down duration was 7.9 ± 8.5 (SD) weeks (26 drying events) from 1985-1994; drying events were less frequent from 1995-2004 (n=11), but increased in duration to 10.0 ± 7.9 weeks (these averages exclude LOKEE 2000-2001 and 1988-

Figure 6-1. Survival for three juvenile size classes and adult-sized apple snails (average shell width 31 ± 4.2 mm SD) in a) flooded tanks and b) dry down tanks after water levels dropped below substrate level in dry down tanks. Gray shaded area in panel a) reflects the post-reproductive die-off (see text for details). Figure from Darby et al. (2008), used with kind permission from Springer Science + Business Media: Wetlands, Dry down impacts on apple snail (*Pomacea paludosa*) demography: Implications for wetland water management, Volume 28, 2008, Pages 204-214, P.C. Darby, R.E. Bennetts, and H.F. Percival, Figure 5, © 2008, The Society of Wetland Scientists.



1990). Although some snails would have died during these events, a large proportion of apple snails, especially adult-sized snails, would have survived the majority of these drying events.

Indirect Effects of Water Depth on Apple Snail Survival: The Role of Predators

Although Florida apple snails exhibit the physiological capacity to survive in dry down conditions, they may suffer mortality from probing predators. Probing predation by birds, including as water levels receded, was reported by Snyder and Snyder (1969). Darby et al. (2004) found that of 23 snails stranded in dry marsh on LKISS, 57% died over a 10-week period from predation, most likely by limpkins, boat-tailed grackles, and/or white ibis that were observed foraging at the site. Considerable uncertainty exists regarding predation effects, given the uncertainty of predicting predator abundance for any location at any given time.

Of course, apple snails are vulnerable to predation in flooded wetlands as well, not only from snail kites, but also from limpkins and grackles (Snyder and Snyder 1969). Hanning (1979) observed 50% predation from boat-tailed grackles on apple snails in enclosed field plots over six weeks (the experiment was designed to estimate female fecundity, not predation). High concentrations of foraging birds could presumably cause a significant decrease in snail abundance, although this has never been quantified. For example, 181 active nests were documented in WCA2B in 1995 (Bennetts and Kitchens 1996a), meaning that over 300 snail kites foraging and feeding their young were consuming snails for the approximate two month egg-to-fledge period. WCA2B is a relatively small wetland (one-tenth the size of WCA3A), so the predation pressure was concentrated in a relatively small area. R. Bennetts (pers. comm.) indicated that the kites nesting in WCA2B were foraging there, not in adjacent wetland units. One year later, approximately 200 kites returned to WCA2B; however, within three weeks 93% of them left (Dreitz and Kitchens 1996). Water levels were relatively high in 1996, so emigration was not due to low water conditions; perhaps the apple snail population had been significantly reduced by the over 300 snail kites nesting and foraging there in 1995. Similarly, localized foraging patches in WCA3A attracted concentrations of snail kites (up to 54), grackles (up to 79), and limpkins (116) in patches of shallow wet prairie (~10-20 cm of water) in January 1994 (Bennetts and Dreitz 1997). Bennetts and Drietz (1997) had evidence that the foraging activities of other birds (hundreds of ibis and herons) disturbed the substrate and water column, increasing the number of surfacing snails vulnerable to kites.

Although avian predators of apple snails have received the most attention, it has long been know that aquatic predators (crayfish, fish, turtles, alligators) consume apple snails (see Chapter 3).

Darby et al. (2009) were the first to study non-avian aquatic predation rates on Florida apple snails. They conducted a series of laboratory experiments to examine predation behavior and capacity to eat snails of a range of different sizes, as well as testing the applicability of the method for tethering snails in the field. [Detailed results of the predator-snail size relationships and lab tethering studies will not be discussed here; see Chapter 3 for aquatic predators studied, and Darby et al. (2009) for details on lab study results]. Darby et al. (2009) placed apple snails in the field, tethering them to PVC poles, to measure predation rates on snails by aquatic predators. They also used wire funnel traps to catch fish, and observed some predators (e.g., turtles) in their sampling sites. Although the tethering process may influence predator behavior (see Darby et al. 2009 for details), their results indicated significant predation pressure on all size ranges of apple snails. Ninety tethering stations were deployed among three sites in WCA2B; 50% of the stations were surrounded by exclosures to exclude predators and estimate non-predation death rates. Tethered snails ranged in size from 4-52 mm in shell length. The majority of apple snails eaten were < 20 mm shell length; no snails in the exclosures died or escaped the tether. There were significant differences in field predation rates depending on snail size and study site. For example, 61% of snails ≤ 10 mm size were preyed upon in Site 1, compared to 38% at Site 2 and 23% at Site 3. Observed average daily predation rates were 1.6% for snails < 20 mm and 1.1% for snails > 20 mm. The relative number of aquatic predators in each site (those found in funnel traps) was also reported (Darby et al. 2009). Although the limited data were not analyzed statistically, they found that higher numbers of fish (e.g., bluegill, mayan cichlids and redear sunfish) and predators observed opportunistically (e.g., soft-shelled turtles) were associated with higher predation rates.

Darby et al. (2009) suggested that one benefit of relatively short drying events (e.g., 4-8 weeks) may be to reduce aquatic predation pressure by reducing the abundance of predators (Trexler et al. 2002, Trexler et al. 2005). Darby (unpublished) compared predation rates similar to those from the field (Darby et al. 2009) to those reduced by 25% (e.g., if aquatic predators in a flooded marsh were reduced in number by a drying event earlier in the season). The calculations assumed no mortality other than from aquatic predation in flooded conditions (which has some support from laboratory studies, Darby et al. 2008), and that each female snail produced 400 eggs (~16 clusters) per season. In the following year, with predation rates of 1.9% (snails ≤ 20 mm) and 1.3% (larger snails), two snails per female would be recruited into the population. Reducing predation rates by 25% (e.g., by a drying event short enough to not impact snail survival, but long enough to reduce aquatic predators) resulted in 11 snails recruited per female. Managing for periodic drying events might not

only be tolerated by apple snails (and benefit the habitat), but enhance survival through reduced predation. Conversely, higher water and longer inundation periods may encourage expansion of snail-eating predators such as Mayan cichlids (common in WCA2B, for example).

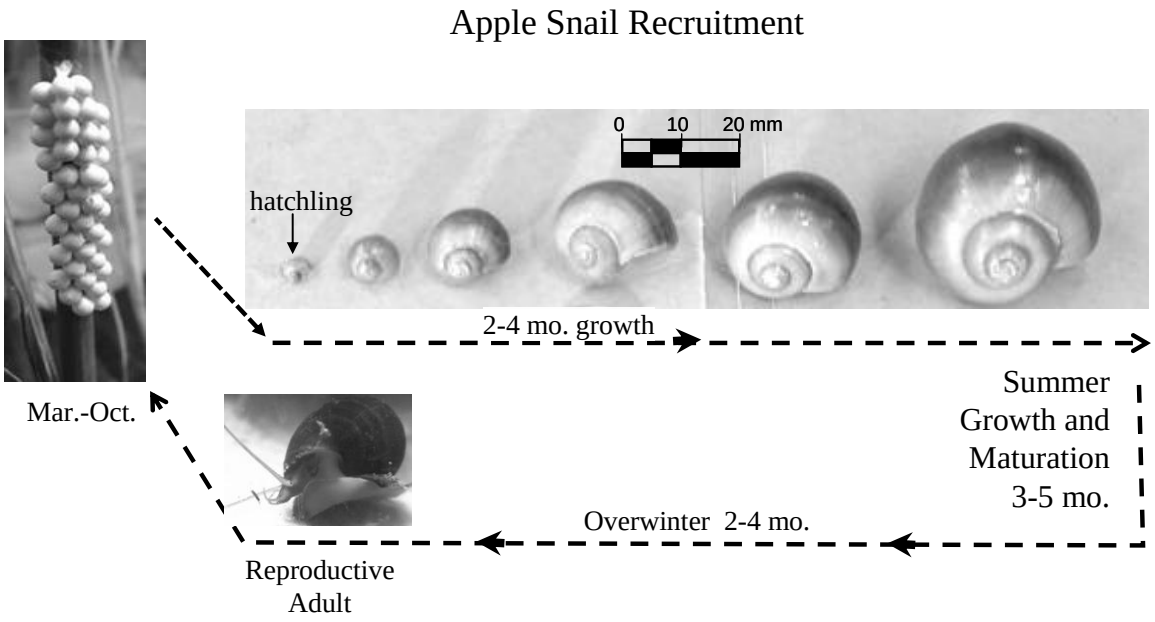
DIRECT EFFECTS OF WATER DEPTH ON RECRUITMENT

Receding Water and Dry Down Effects

Dry downs impact apple snail recruitment— the complete process of egg-laying, hatching, and juvenile growth to reproductively-mature adults (Figure 6-2). By far, the majority of studies have focused on egg cluster production, in part due to the ease of sampling snail eggs. Dry downs directly impact egg-laying because snails quit moving, and, therefore, mating and laying eggs (Darby et al. 2002, Darby et al. 2008). Water management targets should consider the snail breeding cycle. Although snail egg clusters can be found during most of the year, egg production has significant seasonality from year to year and across a range of wetlands. Darby et al. (2008) analyzed the egg cluster count data from Odum (1957), Hanning (1979), and their own data, from Silver Springs, LOKEE, and BCWMA (see Figure 4-4 in Chapter 4). Few to no eggs were found from December to January; egg clusters began to appear in February or early March, and their numbers rose to a peak in mid-spring. Egg production in April-June accounted for nearly 80% of the average annual total. The same pattern was observed in outdoor tanks in controlled studies (Darby et al. 2008). Based on water stage data (1985-2004) for six wetlands (LKISS, OKEE, WCAs 1, 2B, and 3A, and BCWMA), the oviposition peak coincided with the seasonal decline in water levels (Darby et al. 2008). Hanning (1979) and Darby (1998) suggested that receding and/or shallow water promotes egg production, and, citing Odum (1957) attributed some of the seasonality of production to photoperiod. Temperature, as it influences activity in general, most likely has its greatest influence as shallow marshes warm in late winter/early spring, the typical time for initiation of egg cluster production in peninsular Florida. Cool temperatures may delay the onset of egg-laying in the spring (Hanning 1979). This might be an important consideration in relatively cold years in south Florida (e.g., 2010), so that water schedule adjustment might be made to accommodate a delay in the initiation of the egg-laying season (e.g., peak production may be delayed to May or June after relatively cool, wet winters).

From a management perspective, depths less than approximately 10 cm should be avoided in February-June in order to maximize egg cluster production, although we recognize that in the long-run periodic drying events benefit apple snails in other ways. Dry down timing is critical to recruitment, affecting egg production and juvenile survival (Darby et al. 2008). Recruitment may be affected by a

Figure 6-2. Apple snail recruitment starting with egg cluster production (left), hatchling growth to adult size, continued growth and maturation in summer, over-wintering, and completing the cycle with ~1-year-old reproductive adults laying eggs starting in March. Graphic courtesy of Phil Darby, University of West Florida. Scale bar (mm) applies only to the shell growth series.



dry down that occurs during the peak period: 1) through a reduction in total annual egg production (because during a dry down snails stop mating and laying eggs), and 2) by stranding (and eventually killing) juveniles that are too small to survive a lengthy dry down. Short dry downs (e.g., 1-2 weeks) would have little impact (see above material on survival), but as dry downs approach 12 weeks, there is the potential to nearly eliminate the peak egg-laying period. Also, holding water to delay a dry down (if possible) 2-4 weeks could significantly increase juvenile survival in the ensuing dry down conditions, since larger juveniles (~10-15 mm) experience significantly lower mortality than hatchlings (see earlier details on survival). Darby et al. (2008) suggested that the apple snail's early rapid growth equips young-of-the-year snails to survive dry downs that may occur in their juvenile period. Population level impacts from a dry down depend on the proportion of the habitat that goes dry, the duration of the dry down, and the timing of the dry down (Darby et al. 2008). If recession rates can be reduced to postpone an inevitable drying event until June, it would greatly benefit apple snail recruitment in the effected marsh. Although snails can lay eggs within days of recovering from a dry down (Kushlan 1975, P. Darby, UWF, pers. obs.), no information exists on impacts to female fecundity post-emergence. It may be that a population can recover from spring dry down conditions to find suitable depths to support snail recruitment in summer (Wight and Darby 2011).

Rising Water and High Water Effects

An above-water strategy for oviposition in *Pomacea* snails has been attributed to aquatic predator avoidance for the egg stage, and, possibly, avoidance of low dissolved oxygen levels in warm, shallow, tropical wetlands that would impact embryo development (Aldridge 1983). Although apple snails lay their eggs on vegetation above the water line, rising water can submerge eggs. This may explain, in part, why snail egg-laying peaks in the dry season and declines in the summer (Darby 1998). However, altering seasonal water levels in the context of management may flood eggs. Turner (1998) investigated the effects of submergence on egg survival and implications for water management. In a laboratory experiment, he monitored egg development and survival of eggs exposed to air (control) and those submerged in water. Eggs were submerged after being allowed to develop for 1, 4, 8, and 12 days; 1-day-old eggs were fresh and still "jellied," whereas 12-day-old eggs were calcified and generally contained nearly fully developed embryos. Eggs were incubated for 3 weeks. While ~75% of control eggs developed into hatchlings, none of the 1-day, 4-day, or 8-day-old eggs that were submerged hatched (two 8-day-old eggs hatched, but they were exposed to air due to evaporation of water from test chambers). Approximately 65% of the 12-day-old (calcified) eggs

hatched. Turner (1998) concluded that water management should avoid water level rises during peak egg cluster production; otherwise, egg clusters less than 12 days old would perish.

While monitoring apple snail density and egg cluster production in WCA3A, Darby et al. (2005) found that relatively deep water, not necessarily rising water, negatively impacted egg cluster production. Total annual egg cluster production in two transects in one southern WCA3A site in 2002 exceeded 1,600 egg clusters per 1-m x 50-m transect. During this time, depths in southern WCA3A (south of latitude 25° 47') never exceeded ~40 cm from March-June. Adult snail densities exceeded $1/m^2$. During all of 2003, water levels **never fell below 40 cm** in southern WCA3A; adult-sized snail densities continued to exceed $1/m^2$, but total annual egg production declined by an order of magnitude (Darby et al. 2005). The researchers also reported that egg cluster production in shallower sites further north was higher than in the deeper (southern) site. Poor recruitment in 2003 appears to be the cause of an 80% decline in snail densities in four sites sampled in southern WCA3A in 2004 (Darby et al. 2005). These sites were at similar ground elevations and spread out over an approximately 4 km^2 area. Although based on a limited amount of data, this was the first report that snail egg production was negatively affected by relatively high water levels. More data are needed to better define the depths at this upper range (see recommendations for research). It was also the first time that poor recruitment in one year was associated with a significant decline in snail density the following year. Per capita egg production (PCE; total annual egg production divided by snail density) was 11.4 in 2002, but dropped to 0.2 in 2003.

Darby et al. (2009) continued sampling in sites in WCA3A that represented a gradient in ground elevations from north (25° 58') to south (25° 46'). Hydrologic conditions in 2005 were very similar to 2003 (within about 10 cm), but with additional northern sampling, the 2005 data revealed a depth effect across a topographic gradient (i.e., a depth effect on egg production was not an artifact of weather or other conditions). As in 2003, southern site egg cluster production was suppressed (water depths were > 40 cm until May), but sites further north (vicinity of 25°56') showed the typical April peak in production. As in 2003, deeper water in the south shifted the peak in egg-laying to fall. The mechanism behind this peak shift and why egg cluster production (and PCE) fell by an order of magnitude has not been elucidated. It should be noted that egg cluster production did **not** decrease due to high water levels submerging the emergent vegetation available for oviposition; emergent vegetation remained available for snail egg-laying.

In general, the highest apple snail densities and egg cluster counts in WCA3A reported in Darby et al. (2005 and 2009) were associated with hydrologic conditions in 2002, which was a

relatively low water year (southern sites were < 40 cm for ~60 days). With regard to snail densities (>1.0/m^2 in several southern sites), they reflect the previous year (2001) hydrologic conditions, where depths were between 10 and 40 cm for > 100 days (Darby and Wight 2011, also see Chapter 8). Gleason et al. (1975) counted egg clusters at five gauges in WCA3A, WCA2A, and WCA1. They calculated a hydrologic index (average depths x hydroperiod) for each site (p. 36 of their report). They found that the two highest egg cluster counts were associated with the two lowest hydrologic indices, although variation in water chemistry may have contributed to differences in egg counts (p. 86).

Darby et al. (2009) found that apple snail densities (snails/m^2) were relatively low, between 0.02 and 0.40, in all sites monitored in 2005-2007, and that the **proportion** of juvenile-sized snails (those that were ≤ 20 mm) was higher in higher water years. These smaller snails did not reflect current year recruitment, as egg clusters were few or non-existent in study sites; instead, they were snails hatched in the previous (high water) year that had overwintered. Having a high proportion of these small snails may reflect: 1) a shift in the oviposition peak during high water, so that snails hatched in September/October had not grown to adult size by the next March-May sampling period, and/or 2) high water somehow suppressed the growth rate of the snails, even of those hatched the previous spring/summer. The proportion of snails ≤ 20 mm in five southern WCA3A sites was 50-100% in Spring 2004 and followed the 2003 high water conditions. Typically, the proportion of smaller snails in spring is between 10-30% (Darby et al. 2009, Darby unpublished).

Although based on just one sampling site (i.e., Site 14) in WCA3A in 2004, Darby et al. (2005) had some additional evidence to support a possible water depth effect on apple snail growth. Snails sampled from 25 March-14 April consisted of 16% that were > 20 mm shell width. Three weeks later, 47% of snails were > 20 mm (Darby et al. 2005). During that time water depths fell from 49 cm to 38 cm in Site 14. These were not young-of-the-year snails that had hatched and grown to adult size; egg cluster production was zero in March and minimal in April, and not enough time had passed for the few hatchlings to grow to adult size. This was likely the previous year snail cohort that had experienced suppressed growth due to high water conditions throughout 2003 and January-March 2004. In 2006, following a relatively high water year in 2005, Darby et al. (2009) found a higher proportion of larger snails at higher ground elevations (7.54 ft [2.64 m]) compared to lower ground elevations (8.66 ft [2.3 m]). It is possible that the juvenile-sized cohort in 2004 was a function of delayed egg-laying from the previous year, but this could not be determined based on the limited

amount of data. The authors considered a negative effect of increased depth on growth as a working hypothesis that warrants further investigation.

Apple snail density and egg cluster trends in 2002-2007 led Darby et al. (2009) to conclude that impacts on apple snail populations caused by maintaining water depths above approximately 40-50 cm during the breeding season can be direct and immediate (throughout this document we have presented the upper "relatively high" water depth range as 40-*60* cm to reflect reviewer comments, see Z. Welch comments, Appendix B). The overall effects to the snail population were lower overall densities of snails and a higher proportion of juvenile-sized snails, and both of these effects were associated with fewer snails available to support kites. These findings are consistent with the positive effects of low water depths on egg production (especially in the dry season; e.g., Darby et al. 2008, Gleason et al. 1975).

Hydrologic Targets in the Window of Opportunity for Recruitment

The snail kite reproductive season has been described as a shifting window of opportunity constrained by environmental conditions that fluctuate (Bennetts and Kitchens 1997a [Figure 8-10], Kitchens et al. 2002). The same can be said for apple snails. Snail recruitment is affected by temperature and hydrologic conditions. With regards to water temperature, snails become inactive when temperatures drop below 13 °C (Stevens et al. 2002), and the initiation of oviposition in the spring may be delayed by relatively cool temperatures (Hanning 1979). Hanning (1979) concluded that minimum threshold water temperatures of 20-25 °C were essential for snail reproduction. Stevens et al. (2002) found 21 °C (water temperature) was a critical inflection point for increased activity. Darby et al. (2005) found that in the Everglades, the air temperature rise from below 20 °C to the mid 20s occurred in January/February, which coincided with initiation of egg production. [Note that air and water temperatures were found to be highly correlated in these wetlands (see Hanning 1979; Darby unpublished data)]. Photoperiod may also be important (see above). As the season progresses, water depths become the critical feature that influences snail recruitment. Approximately 10 cm was identified as a minimum depth for snail movement, mating, and egg-laying (Darby et al. 2002, 2008). With increased amounts of flocculent material (benthic periphyton, plant debris, etc.), snail movements may be impeded at depths up to 20 cm (P. Darby, UWF, pers. obs.).

At the opposite end of the hydrologic scale, Florida apple snails do not lay eggs under relatively high water conditions (i.e., there appears to be an upper limit of water depth that favors oviposition;

Darby et al. 2005 and 2009). Water depths greater than 40-60 cm appear to suppress egg production (see description in previous section). In years with greater depths, snail egg production is not only delayed, but also reduced in magnitude (as evident by PCE, see previous section). [Again, note that egg cluster production did not decrease due to high water levels submerging the vegetation available for oviposition; emergent vegetation remained available for snail egg-laying]. Therefore, as temperatures rise, water management in support of snail reproduction should target water depths that gradually fall from February through June so that depths range from approximately 40-60 cm down to 10 cm for as much time as possible (the four highest monthly PCE values recorded in WCA3A from 2002-2007 were associated with 10-40 cm depths). Since these observed trends were based on a limited amount of data, but the effects appear to be potentially very influential, additional research is recommended (see Chapter 11). The greatest window of opportunity for recruitment for the Florida apple snail consists of water depths approximately 40-60 cm (beginning in February/March) down to no lower than 10 cm in May-June, with typical spring-summer temperatures.

APPLE SNAIL VEGETATION NEEDS

Juvenile Snail Growth and Vegetation

Here, we focus on apple snail growth rates as related to diet; see Chapter 4 for a list of the plants snails eat. In a study by Sharfstein and Steinman (2001), juvenile Florida apple snails hatched in the lab (from eggs collected at LOKEE) were fed *Utricularia*-periphyton (species of *Utricularia* not provided), *Eleocharis*-periphyton, and metaphyton (loose benthic periphyton). Prior to the start of the 32-day experiment, snails were 7-14 mm in length. One hundred and twenty snails were randomly distributed in twelve 11-liter (L) aquaria, in which water temperatures ranged from 18 to 22 ºC. Snails grew and survived significantly better when fed the *Utricularia*-periphyton complex vs. metaphyton. Increases in mean wet mass and length were 0.36 grams and 2.15 mm for the *Utricularia* treatment, compared to 0.15 grams and 0.6 mm for the metaphyton treatment, and survival was 100% compared to 82.5%, respectively (Sharfstein and Steinman 2001). There were no significant growth differences between either the *Utricularia*-periphyton vs. *Eleocharis*-periphyton treatment or the *Eleocharis*-periphyton vs. metaphyton treatment. *Utricularia*-periphyton had a relatively low carbon to nitrogen ratio and ash content, as well as high phosphorus and chlorophyll concentrations, suggesting that it had the highest nutritional quality of the three (Sharfstein and Steinman 2001). Changes in snail biomass and length in the study were positively correlated with treatment chlorophyll concentration and phosphorus concentration, and snail biomass changes were inversely

correlated with snail excreta nitrogen content. The authors pointed out that changing hydroperiods and eutrophication over the last few decades had led to changes in LOKEE littoral zone vegetation, and that threats exist to both *Eleocharis* stands and the *Utricularia*-epiphyton assemblage (Sharfstein and Steinman 2001). Note that increased phosphorus levels can lead to the break-up and disappearance of calcareous floating mats of periphyton (McCormick et al. 1998). Liston and Trexler (2005) found three genera of snails (size classes not reported, and no *Pomacea* snails) in floating periphyton mats that frequently included *Utricularia purpurea*. Additional studies would be required to assess the role that *Utricularia*-periphyton complexes play in supporting *Pomacea* snails.

A similar study by Shuford et al. (2005) focused on food sources and habitats in the Everglades. They used apple snails hatched from eggs collected in WCA2A, and compared growth in juvenile snails fed benthic periphyton vs. sawgrass detritus (no epiphytic periphyton attached). Hatchling snails were allowed to grow for at least 21 days before starting the experiment; seven individuals were placed in each of the twelve 15-L aquaria. Aquaria with sawgrass detritus were covered with shade cloth to provide 50% shading (to mimic shading in natural sawgrass stands). The experiment ran for 30 days, after which survival and the mean aperture length, shell length, and wet weight were determined for each aquarium's snails. Snails fed periphyton had shell lengths and wet weights that increased at twice the rate of those fed detritus. The authors concluded that juvenile Florida apple snails can grow by consuming resources in slough (represented by periphyton) and sawgrass habitats, but that the faster growth of snails eating periphyton in their study suggested that sloughs were preferred over sawgrass habitat as an apple snail "nursery." Karunaratne et al. (2006) disagreed with this conclusion, because the food representing sawgrass habitat in the Shuford et al. study was only sawgrass-based detritus. Sawgrass has been described as a preferred macrophyte for epiphytic periphyton (Browder et al. 1994), and periphyton commonly coats submerged sawgrass where snails lay eggs in the Everglades (P. Darby, UWF, pers. obs.). Consequently, the sawgrass-epiphyton complex may be important for hatchling apple snail growth. Also note that Shuford et al.'s characterization of slough habitat was that it was dominated by periphyton; this differs from work by Karunaratne et al. (2006) and Darby et al. (2005), in which slough habitats were characterized by white water-lily (*Nymphaea* sp.) and follow the descriptions of Loveless (1959), and often did not have lush periphyton growth (L. Karunaratne and P. Darby, UWF, pers. obs.). They also pointed out that snails likely need different habitats at different times in their life cycle, and that maintaining a mosaic of habitats is important (i.e., the slough-sawgrass mosaic).

The specific growth rates in the Shuford (2005) and Sharfstein and Steinman (2001) studies, regardless of diet provided, were relatively low and likely influenced by the density of snails in their experiments. Whereas snails in these studies grew a total of ~1-2 mm in 3 or more weeks, Glass and Darby (2009) reported growth rates of 2-3 mm per week (the effects of calcium and pH, the focus of Glass and Darby [2009] are discussed below). Glass and Darby (2009) monitored juvenile snail growth with 4 snails per 32 L (8 L/snail) compared to 2.14 L/snail (Shuford et al. 2005) and 1.1 L/snail (Sharfstein and Steinman 2001). Hanning (1979) reported similarly low growth rates in his aquaria studies (0.4 L/snail), and he alluded to a density dependent effect. Conner et al. (2008) reported highly significant density dependent growth suppression in Florida apple snails. The mechanism behind this growth suppression has not been elucidated; in other aquatic prosobranch snails, intra-specific growth inhibiting chemicals were found in slime trails (Williamson et al. 1976). Hanning (1979) also estimated field growth rates using size-frequency data that indicated growth rates of 13.2 mm/month (~3.1 mm/week). Knowing the apple snail's potential growth rate may be important as research continues on habitat conditions to target to maximize recruitment in a recovering snail population.

Egg-laying and Vegetation

Of those available, the emergent plant species most used for oviposition in the BCWMA (=SJM) were sawgrass, swamp lily (*Crinum americanum*), pickerelweed, and lance-leaved sagittaria (*Sagittaria lancifolia*); apparent preference was for emergent plant structures generally > 6 mm in diameter at the water's surface (Turner 1996). Egg height above water did not differ among vegetation types, nor did clutch size (Turner 1996). Turner examined the distribution of egg clusters among emergent plants by sampling 25 100-m-long transects in four plant associations (sawgrass marsh, maidencane marsh, mixed shallow marsh, and deep marsh). Data were collected on the frequency of plant stems and the density of egg clusters. Sawgrass sites were dominated by sawgrass, and because preliminary sampling indicated that few egg clusters were laid within dense stands, egg clusters were counted near the outside edge of the stand (i.e., the ecotone), up to 1 m into the stand. In maidencane marsh sites, more than one-half of stems were maidencane and about one-third were Gulf Coast spikerush (*Eleocharis cellulosa*). Mixed shallow marshes had the highest stem densities of the four plant associations and were dominated by slim spikerush (*Eleocharis elongata*), followed by lance-leaved sagittaria, maidencane, and pickerelweed. [Technically, some of these stem counts were actually counts of emergent petioles, or leaves, depending on the plant species]. Deep marsh

sites were sparsely vegetated with spikerush (*Eleocharis* spp). Results indicated that egg cluster densities were highest in sawgrass marsh (the ecotone), intermediate in maidencane marsh and mixed shallow marshes (about one-third of those in sawgrass), and lowest in deep marsh. Although not the most common species in the maidencane marsh, most egg clusters were laid on lance-leaved sagittaria, swamp lily, and pickerelweed. Similarly, although lance-leaved sagittaria and pickerelweed were the second and fourth most abundant plants recorded, respectively, within the mixed shallow marsh, these two plants contained most of the egg clusters in this habitat. Although Turner (1996) did not study the reason for the observed preference for broad-stemmed (or broad-leaved/petioled) plants for oviposition, he suggested it may be because the larger diameter stems would provide better "footing" for female snails that must both climb the stems and hold their positions for one or more hours to deposit their eggs. The broader stems would also be less likely to bend under the weight of the snail, and would provide more surface area for the deposited egg clutch.

Based on what was learned about the apple snail's oviposition needs, as well as other biological needs that remained unclear (e.g., preferred diet), Turner (1996) recommended that management of apple snail habitat should promote a heterogeneous community of emergent plants, especially with structures > 6 mm above the water surface, at moderate densities.

A study in littoral zone habitat on LKISS yielded results similar to Turner's (1996) regarding preferences for plant species for oviposition. Data were collected on the occurrence of vegetation types and on the distribution and abundance of egg clusters among the vegetation types in four sites (Darby 2006). Five emergent vegetation types (pickerelweed, torpedo grass [*Panicum repens*], bulrush [*Scirpus* sp. {now *Schoenoplectus* sp.}], Egyptian paspalidium, and alligator weed [*Alternanthera philoxeroides*]), which experienced similar hydroperiods (except that paspalidium grew in deeper water), were present in the sites. Egg clusters were found on all vegetation types, but snails did not use emergent plants for oviposition in proportion to the plants' occurrence (with some site to site variation). Pickerelweed was used most often for oviposition, and it was used at disproportionately high levels. Forty-five to 61% of egg clusters recorded were on pickerelweed; 22-38% of the total were on bulrush; 10-20% were on Egyptian paspalidium; and only small proportions of egg clusters were found on alligator weed (< 3%) or torpedo grass (< 2%). Like pickerelweed, bulrush was used more frequently than expected based on its availability, while paspalidium was used less than expected based on its availability. Alligator weed and torpedo grass were consistently avoided (considering their relative dominance in the plant community). In the sites studied, apple snails showed a strong preference for laying eggs on pickerelweed and bulrush (Darby 2006).

In WCA3A and WCA1, Karunaratne et al. (2006) found no snail eggs on white water-lily leaves in water-lily-dominated slough, but, similar to Darby (2006) and Turner (1996), many egg clusters were found on maidencane, paspalidium, and lance-leaved sagittaria in wet prairie habitat and along the sawgrass ecotone. A quantitative assessment of preference (which requires measuring habitat types available) was not reported for the WCAs.

Apple Snail Densities in Different Vegetation Types

Vegetation in the Everglades

Wet prairie habitats (dominated by emergent grasses and sedges) in WCA3A and WCA1 were found to support greater densities of Florida apple snails, often two to three times greater, than slough habitats (those dominated by white water-lily; Karunaratne et al. 2006). [Habitat designations of "wet prairie" and "slough" used by Karunaratne et al. followed Loveless (1959)]. Field sampling included three sites in WCA1 and five sites in WCA3A. Samples were taken from juxtaposed patches of different habitats within a site; the differences were not site to site differences where different sites were dominated by one or another habitat type. The authors suggested that the habitat preference reflects vegetation that supports snails in breathing air and laying eggs. Emergent stems that snails use to reach the water surface for aerial respiration (Turner 1996) are more abundant in wet prairie compared to slough. For laying eggs, the emergent vegetation must support an egg-laying female as she climbs several inches above the water. Snails find both of these needs met in wet prairie habitat (although not all emergent species support egg-laying). Crayfish have also been found to be more abundant in wet prairie than slough (Jordan et al. 1996a, Karunaratne et al. 2006), possibly due to the greater complexity of the habitat (associated with emergent plants) that deterred predation by fish (Jordan et al. 1996b). The important positive effect of emergent plants was noted in white water-lily-dominated slough habitat containing the emergent species swamp lily (*Crinum americanum*). Snail densities were almost four times higher (density = 0.36 ± 0.10 snails/m^2) in traps containing swamp lily and white water-lily, compared to those containing white water-lily leaves only (Karunaratne et al. 2006).

Wet prairies dominated by certain species of emergent plants, as well as different densities of plants, also affect apple snail densities. For example, wet prairies dominated by maidencane generally had greater densities of snails than those dominated by Gulf Coast spikerush (Karunaratne et al. 2006). Also, fewer snails were found in high stem density Gulf Coast spikerush (56.2 ± 2.7 SE stems / 0.5 m^2) compared to lower stem density Gulf Coast spikerush (27.7 ± 0.8 SE stems / 0.5 m^2).

[Note that plant species and differences in plant densities also influence snail kite foraging, so what might be best for snails may not be best for kites, see Chapter 7].

Vegetation in Rivers and Lakes

Habitat and snail abundance relationships have also been reported in areas outside of the Everglades. Bryan (1990) found more snails in beds of tape grass (*Vallisneria americana*), compared to areas containing water hyacinth (*Eichhornia crassipes*) or water lettuce (*Pistia sp.*) mats, in a spring system. Corrao et al. (2006) found snail densities of 4.8/m^2, some of the highest ever documented, on Wacissa Springs in tape grass-dominated habitats.

Prior to a drawdown of LKISS in the mid 1990s, Florida apple snails were found at higher densities in sites having predominately sand substrates and dominated by emergent plants (Darby et al. 2004) compared to yellow-cow lily (*Nuphar luteum*) -dominated areas. Darby et al. (2004) found no snails associated with yellow-cow lily*;* these sites had unconsolidated organic substrates and no submerged aquatic vegetation (SAV). After the drawdown, the number of snails decreased dramatically in nearly all of the sites with sandy substrates; however, in some of the sites that had unconsolidated organic substrates before the drawdown, more (but still few) snails were recorded 6-12 months after the drawdown and "muck" removal activities (compared to before the drawdown/"muck" removal). Several years later (Spring 2008), one of the yellow cow-lily sites had consolidated substrates, supported abundant SAV, and had snail densities of 0.38/m^2 (P. Darby, unpublished data). Note that snails can lay eggs underneath the flowers or leaves of yellow cow-lily when the flowers/leaves emerge above the water; snails do not lay eggs on white water-lily lily pads and flower stems, which do not emerge above the water.

Investigators and managers learn from what apple snails prefer, but also from what habitats snails appear to avoid (e.g., with unconsolidated substrates in yellow cow-lily habitats on LKISS). Darby (2006) also found very few or no snails (17 snails in 1,000 total traps) in high density, monoculture pickerelweed on LTOHO prior to drawdown and habitat restoration in 2001-2003. No snails or snail eggs were observed on floating mat pickerelweed. After the 2004 drawdown and vegetation scraping, *Pomacea* snails moved into the improved littoral zone habitats; unfortunately, the snails were exotic (see below), but they provided an indication of habitat improvement.

Kitchens et al. (2008) reported site occupancy (based on presence/absence data) of native and exotic snails after the LTOHO drawdown and habitat restoration (i.e., scraping and removal of pickerelweed mats). Consistent with Darby (2006), they found that site occupancy by the exotic snail

increased from 0% prior to the drawdown to 45% and 83% one and two years after the drawdown, respectively. They also found that native snail occupancy of their sites decreased, from 66% occupancy in 2002 to 13% after the drawdown. Kitchens et al. reported that occupancy rates for native snails increased to 80% by 2006. Occupancy rates two years after lake treatment, for both exotic and native snails, suggested that the 2004 LTOHO drawdown and habitat restoration benefited *Pomacea* snail populations. Note that occupancy provides no information on density or relative abundance, such that one snail captured in a site would indicate presence, but associated low densities may not be sufficient to support foraging snail kites. For example, over the same period in which Kitchens et al. sampled, Darby (2006) reported native snails in two sites on LTOHO with densities ranging of 0.02 and 0.16 per m^2 (relatively low in terms of a kite foraging base, see Chapter 7); they found no snails in a third site.

Apple snail vegetation preferences were reported in Darby (2006) for sites on LKISS. The highest snail densities were found in relatively low density pickerelweed patches. The other most common emergent plant species in throw trap samples were torpedo grass, Egyptian paspalidium, and alligator weed. The vegetation in which apple snails were sampled had similar hydroperiods. In addition to having the highest snail densities, pickerelweed was most used for oviposition (as described previously), which may explain why both adults (mating and laying eggs) and juveniles (hatching from the eggs) were found more often in this habitat. Although paspalidium was used for oviposition, no juveniles were found in this habitat type. This plant type was associated with deeper water (also see Welch 2009), had no other associated emergent plants, and had few submerged species and little periphyton. As far as SAV, Darby (2006) found the highest densities of both adults and juveniles associated with tape grass, although the effect was statistically significant only for juvenile snails. A combination of pickerelweed and tape grass supported the highest snail densities on the lake. The other most common submerged plants in throw traps were water grass (*Luziola flutans* [=*Hydrochloa caroliniensis*]), rooted hydrilla (*Hydrilla verticillata*), and lemon grass (*Bacopa* spp.).

WATER CHEMISTRY AND CONTAMINANT EFFECTS ON APPLE SNAILS

Given their need for calcium for shell growth, it is not surprising that greater Florida apple snail abundances have been associated with higher calcium levels. On Lake Woodruff (Volusia County), Hurdle (1974) found the greatest number of egg clusters in alkaline waters where alkalinity was expressed in mg/L calcium carbonate ($CaCO_3$); the number of eggs dropped dramatically as alkalinity and pH decreased. Glass and Darby (2009) found significantly higher growth rates and

higher crush weights (i.e., stronger shells) in apple snails grown in the lab in water with pH of 8.0 and calcium ion concentrations ≥ 28 mg/L (similar to levels in southern WCA3A). Their findings were consistent with field data that show relatively low snail densities in areas with low pH and low calcium concentrations (e.g., WCA1, see Darby et al. 2005). Although some areas may not be capable of providing **ideal** pH and calcium levels to support snail populations, snail kites, limpkins, and other snail predators still use these areas for both nesting and foraging (e.g., WCA1).

In the past, questions were raised about potential effects of nitrate as a possible explanation as to why apple snail populations dramatically declined in some Florida springs (Corrao et al. 2006). Corrao et al. (2006) found relatively high apple snail densities in the springs (4-5 snails/m^2), where average pH values were 7.0-8.0 and Ca^{2+} was consistently between 40-60 mg/L (Scott et al. 2002). In terms of a nitrate effect, their field and lab studies found that nitrate levels (ranging from 0.6-3 parts per million [ppm]) in six spring-fed river systems (Jackson Blue, Rainbow, Alexander, Wakulla, Wacissa, and Ichnetucknee) did not influence snail densities in the springs, nor did the same nitrate levels affect snail growth or survival in the lab (Corrao et al. 2006). Only at nitrate levels orders of magnitude higher than those found in springs did they observe negative effects on snail survival and growth.

Some study of both mercury and organochlorine pesticide residues in apple snails have occurred out of concerns for snail kites. Studies found that mercury residues in snails' soft tissues were generally low (0.062 ppm, on average), although snails may serve as an indicator of bioavailable mercury in central and south Florida wetlands (Eisemann et al. 1997). In a study of a small number of apple snails (fewer than 20) from Palm Beach County, researchers analyzed snails for organochlorine pesticides (e.g., DDT, DDE, dieldrin; Rumbold et al. 1996). No organochlorine compounds were found in any of the snail samples.

Elevated copper levels have been measured in south Florida surface water, sediment, and biota (Schuler et al. 2008). The metal has also been placed by the U.S. Environmental Protection Agency (EPA) among the top metals of water quality concern in the U.S. However, little is known of its potential ecological risks (Schuler et al. 2008). Here, we provide a brief summary of the potential for copper to impact snail populations.

In the 1980's it was suggested that copper-diquat formulations applied to canals (to kill hydrilla) were responsible for a decline in the apple snail population in the LNWR (Imlay and Winger 1983). Concentrations of copper lower than those applied at the refuge (1 mg/L) were found to kill snails of four families (*Physidae, Lymnaeidae, Planorbidae, Viviparidae*) in other studies. Imlay and

Winger (1983) did not report any observations involving apple snails, but they concluded that copper-based herbicide formulations should be reduced or not applied to waters with apple snails that support foraging kites. Winger et al. (1984) assessed the toxicity of copper-diquat and chelated formulations of copper on hatchling apple snails, using a range of copper concentrations and food and substrate treatments. Toxicity levels were reported as 96-hr LC50s (the copper concentration that killed 50% of snails in 96 hours). For treatments in the lab containing food and/or substrate (which were more comparable to field conditions), 96-hr LC50 readings ranged from approximately 20-100 ug/L. However, copper-diquat field applications to hydrilla had no effect on the survival of caged Florida apple snail adults and hatchlings, thus indicating that hydrilla copper-diquat treatments (applied at recommended concentrations) were probably not responsible for the decline of the apple snail in LNWR.

There is also the potential for copper to affect apple snails as former agricultural lands are re-flooded for wetland restoration; copper from agricultural applications binds to soils. Under the guidelines of CERP, thousands of acres of citrus agriculture lands will be inundated, some with soils containing copper concentrations up to 1,200 mg/kg dry weight (SFWMD 2001-2006). Several recent publications have explored the effects of copper on apple snails in this context (e.g., Hoang et al. 2008a and 2008b, Rogevich et al. 2008a, Hoang et al. 2009). Hoang et al. (2008b) reported that hatchling apple snails that were exposed to water with 14 ug Cu/L for 28 days concentrated the copper by more than 1,000-fold. These researchers also found that copper accumulated in adult snails through the soil (via direct contact and possibly ingestion) and, especially, contaminated food. They concluded that bioaccumulation in soft tissues might put snail predators at risk of copper exposure from consumption of snails that colonize flooded agricultural areas.

Rogevich et al. (2008a and 2008b) estimated a 96-hr LC50 for copper in 2- to 30-day-old hatchlings as 34-44 ug/L, and for adults (120-day-old) as 141-182 ug/L; these LC50s reflect low pH and dissolved organic carbon (DOC) concentrations expected to be associated with flooded agricultural fields. Estebenet and Cazzaniga (1990), studying *Pomacea canaliculata*, also reported that copper toxicity was size/age dependant. Chronic studies with 16 ug/L Cu resulted in: 1) significantly slowed juvenile growth rates in the first two months (1.69 mm vs. 2.18 mm total length/wk for the control), 2) significantly reduced egg cluster production (by about 30% compared to the control), and 3) significantly reduced hatch success (approximately 30% in Cu treatments vs. 67% in controls [actual number not reported]).

Schuler et al. (2008) conducted a screening-level aquatic risk assessment for copper in freshwater environments of south Florida. They concluded that potential acute risks to aquatic organisms from copper were low, but the potential for ecological risk from chronic exposure to copper were high in areas with applications of the fungicide copper hydroxide (associated with citrus agriculture).

CHAPTER 7: THE INFLUENCE OF APPLE SNAIL ABUNDANCE ON SNAIL KITE FORAGING AND IMPLICATIONS FOR KITE DEMOGRAPHIC SUCCESS

INTRODUCTION

A number of studies have looked at aspects of snail kite foraging (e.g., how they forage, where they forage, the amount of time spent on foraging bouts), but few researchers have quantified connections between apple snail densities, or other direct measures of prey availability, to kite foraging. Although relative abundance and indirect measures of snail abundance (e.g., capture rates) provide helpful information on foraging ecology (e.g., see Beissinger and Snyder 1987), the actual prey density is of importance to the species. Misconceptions about apple snail availability have resulted from a lack of information on snail density. If snail kites abandon an area, is it because of changes in snail density, changes in water depth, changes in habitat, or some combination of these factors? As we manage wetland units to support kites, and if we have no kites in the area to indicate foraging success, then knowing snail density helps us assess habitat quality and may trigger management actions to increase snail density (e.g., targeting water depths to increase snail reproduction). Knowing what constitutes a sufficient prey abundance (and/or density) to support snail kite foraging also provides restoration targets (e.g., a minimum snail density and acreage of suitable foraging habitat) for designated critical wetland units that have largely been abandoned by kites. Finally, knowing apple snail density helps us better understand kite foraging ecology; if we know sufficient prey densities exist in a wetland, then we can examine other conditions that have a positive or negative effect on foraging success (e.g., vegetation, see Bennetts et al. 2006).

The primary reason for the limited data on apple snail availability associated with snail kite foraging comes from past perceptions of the difficulty in estimating snail density. Throw trap sampling requires considerable labor (see Darby et al. 1999), and mark-recapture techniques require significant equipment costs ($2,000-$3,000 for traps per site sampled) and time (2-4 weeks) to obtain a sample (Valentine-Darby et al. 2008; also see http://www.pomaceaproject.org/methods.asp for details and comparison of different sampling methods). Darby and colleagues have relied primarily on throw trap sampling after years of experience and modifications to improve sampling efficiency. However, as mentioned, some indirect measures of snail abundance (which have appeal due to relative ease and little resource investment) have provided some important information on kite ecology, and will be addressed here.

INDIRECT MEASURES OF APPLE SNAIL ABUNDANCE & ASSOCIATION WITH SNAIL KITE DEMOGRAPHY

Two studies that used indirect measures of snail abundance to examine aspects of snail kite nesting were Beissinger and Snyder (1987) and Bennetts et al. (1988). In their study of mate desertion in the snail kite, Beissinger and Snyder (1987) used the distances that kites traveled to forage as a measure of snail abundance. Later, Bennetts et al. (1988) reported that, as the nesting season progressed, foraging distances increased. This may have indicated that the snail resource was becoming depleted in the immediate area, and supported the approach taken by Beissinger and Snyder (1987). The authors assumed an inverse relationship between the foraging distance and snail abundance, such that the farther kites traveled to forage, the lower the snail availability in the area. Beissinger and Snyder (1987) were interested in the concept of ambisexual mate desertion, a reproductive strategy used by snail kites faced with boom (wet years with plenty of snails) or bust (drought years) conditions in a highly dynamic landscape. They found that one parent was likely to abandon a nest, leaving the other to complete the fledging process, when snail abundances (as measured by distance traveled to forage) were relatively high. If snail abundances were relatively low (longer distance traveled to forage), then both parents were needed to successfully fledge young. A significantly higher percentage of kite nests were deserted (which allows the deserter an opportunity to nest again) by one of the kite pair when the foraging range was small.

A study of nesting success and nest-site selection in WCA3A in 1986-1987 also used snail kite foraging (time) as an indirect measure of apple snail abundance. The goal was to examine the relationship between snail abundance and nesting habitat selection (Bennetts et al. 1988). One of three methods or indices used to estimate snail abundance was the time it took a kite to capture a snail (capture time), which was defined as the time from when a kite left a perch to forage until a snail was caught. Similar to Beissinger and Snyder (1987), it was assumed that longer capture times (like longer distances traveled) indicated lower snail abundance. [Bennetts et al. 1988 also used egg cluster counts as an index of snail abundance, see below]. The potential problems with using foraging time as an index of snail abundance were pointed out (e.g., times could be affected by vegetation, season, temperature, time of day, precipitation, and wind), and Bennetts and colleagues controlled for these conditions (e.g., no observations were made during high winds) to avoid misinterpreting their capture time data. Bennetts et al. (1988) also directly measured apple snails in two sites using 1-m^2 throw traps (a similar protocol as outlined in Darby et al. 1999).

Relative snail abundances (via capture times) were estimated in areas of high snail kite nesting (areas with a total of at least 10 occupied kite nests in an approximately 1-km-radius area) and low kite nesting (a total of ≤ 5 nests). Bennetts et al. (1988) hypothesized that the areas with greater densities of nesting snail kites would have shorter apple snail capture times. However, no significant difference in capture times in high- vs. low-nesting-density areas was found, and results from the work were inconclusive. Although there was no conclusive evidence of the importance of snail abundance in kite selection of nesting habitat, there were some indications that kites tended to nest in higher densities where snails appeared more abundant. Although the difference was not significant, apple snail density estimates were higher where more snail kites nested (0.65 snails/m^2 [± 1.04 SD]), compared to where fewer kites nested (0.45 snails/m^2 [± 0.60 SD]). Bennetts et al. (1988) concluded that "a minimum abundance of snails obviously is required in order for kites to survive and breed in an area; however, the relative importance of apple snail abundance above this minimum threshold as a selection criterion of nesting habitat remains unclear."

Egg cluster counts have appeal as a measure of relative snail abundance because they are easy to observe (deposited on vegetation above the water line) and easy to quantify (PVC quadrat counts, see Darby et al. 1999). Bennetts et al. (1988) counted egg clusters and related them to kite nest density (>10 or ≤ 5 nests within 1-km radius) and snail capture times. Egg cluster indices, except when particularly low, did not relate to capture times (low indices, <0.5, were associated with long capture times, but all egg cluster indices from 1 to 4 had no influence on capture time). Egg cluster indices were higher in higher snail kite nest areas.

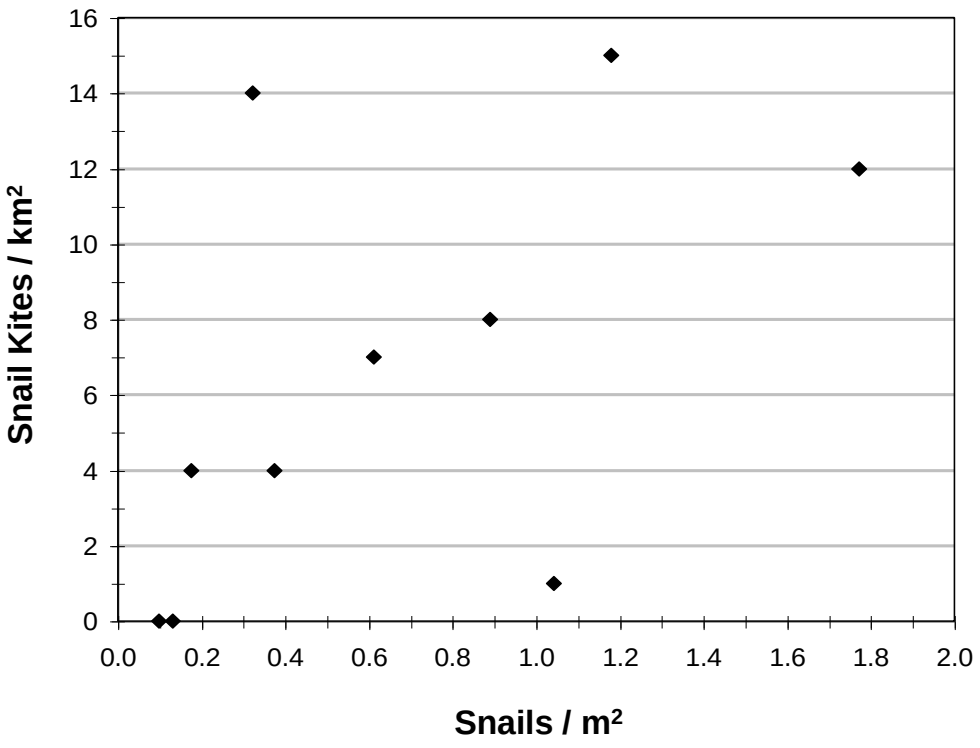
Darby and Ren (2004) related egg cluster counts to apple snail densities estimated by 1-m^2 throw traps to evaluate the utility of egg counts as a reliable index of snail abundance. Although egg cluster counts increased with snail density (not statistically significant), snail density explained only 23% of the variation in egg counts; a 3.5-fold increase in snail density (from 0.10 to 0.35) resulted in only a 20% increase in egg counts. Darby et al. (2005) found that egg cluster counts were sensitive to water depth, and many factors other than snail density may influence egg counts (e.g., food quality, calcium levels, parasitism, etc.). Their utility in assessing habitat quality continues to be explored, but relying on egg counts as an index of snail abundance has significant limitations.

DIRECT MEASURES OF APPLE SNAIL ABUNDANCE & CONNECTIONS TO SNAIL KITES

Bennetts et al. (1988) was the first to examine apple snail density in relation to snail kites, but they had data from only two sites in WCA3A (see previous section). Their snail sampling methods were based on work by Owre and Rich (1987), who used a portable suction dredge to extract snails; Bennetts et al. used the dredge in a 1-m^2 wire mesh frame. The standard protocol for using 1-m^2 throw traps and estimating snail density has since been well developed and applied to dozens of studies on snails and kites (Darby et al. 1999, Corrao et al. 2006, Bennetts et al. 2006, Karunaratne et al. 2006, and many technical reports from Darby and colleagues).

Darby et al. (2006) reported apple snail density estimates in wet prairie habitats collected in 1995-2004. Information on the presence/absence of foraging snail kites was also available for the 1995-2004 period, and the authors conducted a systematic survey in 2002-2003 in which they sampled snail densities and recorded associated numbers of foraging kites. Snail density estimates were provided for 30 sites in five wetlands throughout central and southern Florida (Darby et al. 2006). Sampling sites were described as wet prairie / shallow marsh habitats at BCWMA, WCA3A, WCA1 (within LNWR), LNWR impoundments, and LKISS. Site selection criteria were based on descriptions of suitable kite foraging habitat (e.g., Sykes et al. 1995, Bennetts et al. 2006). In 18 of the 30 sites, in WCA3A and WCA1, the authors had both snail density data and the number of individual kites foraging within a 1-km^2 area from the center of the snail sampling site (collected using systematic transects conducted by airboat). For the remaining 12 of 30 sites, only a record of presence or absence of foraging snail kites was available; therefore, the authors reported these data separately and excluded them from the test for an association between snail density and numbers of foraging kites. Average snail density estimates ranged from 0-1.8 (± 0.25 SE) snails per m^2 among the 30 sites (Darby et al. 2006). Foraging snail kites were not observed at any locations that had a density estimate of 0.14 snails per m^2 or less. More than five foraging kites per km^2 were recorded only where apple snail densities were greater than 0.32 snails/m^2. Analysis of the data from the systematic surveys in WCA3A indicated a positive association between snail densities and the number of foraging snail kites (Spearman $r = 0.76$, $n = 12$, $P = 0.016$; Figure 7-1). Darby et al. (2006) concluded that when kites have options among foraging patches (i.e., some with relatively high vs. lower snail density), sustained kite foraging requires a minimum apple snail density of 0.14 snails per m^2 (later expressed as ~0.1 to 0.2 in reports, e.g., Darby et al. 2009).

Figure 7-1. Number of snail kites counted within 1 km^2 in WCA3A in relation to the mean number of apple snails per m^2 of wet prairie habitat. Figure from Darby et al. (2006), used with kind permission from the Florida Ornithological Society: Florida Field Naturalist, Apple snail densities in habitats used by foraging snail kites, Volume 34, 2006, Pages 37-47, P.C. Darby, R.E. Bennetts, and L.B. Karunaratne, Figure 2.



Darby et al. (2006) provided evidence that snail kites concentrate in foraging patches with higher densities of snails. However, the authors also caution against using kite use of an area as an indication of habitat quality or relative snail abundance. Although foraging kites and snail density were positively associated, they also observed only one kite foraging in a high snail density site (> 1 snail/m^2) and several kites foraging in a relatively low snail density site (four kites in 0.18 snails/m^2 ± 0.02). Snail kites show nomadic tendencies, including exploratory behavior in search of potential foraging areas (Bennetts and Kitchens 2000). Also, nesting kites may be constrained to a local area (even as prey availability decreases) as they stay committed to fledging young. Snail kites may also have to take time to assess profitability of a site, through foraging, before moving to a more productive site (Bourne 1985a, Darby et al. 2006).

Darby et al. (2012) made direct observations of snail kites foraging on native apple snails in sites with a narrow range of water depths and vegetation types. They were interested in whether significantly more flight time (and therefore energy) was required to capture snails in low (e.g., ≤ 0.1-0.2/m^2) versus higher densities. The overall objectives were to quantify capture times (time spent in flight to capture a snail, as in Sykes 1987b and Bennetts et al. 1988) associated with snail densities, and to identify snail densities that result in successful kite foraging bouts. They measured the time to capture a snail (capture times) at 10 sites on central Florida lakes (sampling two sites twice over different years) and five sites in wetland units of the Everglades. Capture times exhibited an inverse asymptotic relationship to snail density (Figure 7-2). As apple snail density increased from ~ 0.1 to 0.2 snails per m^2, capture times declined from ~ 600 to 200 seconds; capture times leveled off to ~ 75 seconds between 0.4 to1.4 snails per m^2. Capture times and associated snail densities from Bennetts et al. (1988) were very close to the predicted relationship evident from the non-linear regression reported in Darby et al. (2012). Habitat characteristics (water depth, plant densities) had no effect on capture times; the authors intentionally selected a narrow range of habitat conditions in order to focus on the influence of snail density, but they included water and vegetation in their analyses rather than assume no effects. Snail kites only ended foraging bouts without a snail in sites with snail densities < 0.2 snails per m^2 (Figure 7-3). The Darby et al. (2012) data were consistent with the numbers of kites found foraging over a range of snail densities. Darby et al. (2006) found no snail kites foraging in WCA sites where apple snail densities were ≤ 0.14 snails per m^2. Although Darby et al. (2006) concluded 0.14 per m^2 may be a minimum threshold prey density, the kites in the vicinity had options to forage in other nearby sites with higher snail densities (up to 1.77 per m^2). This was not the case in Darby et al. (2012), where in all 11 WCA sites sampled, prey densities were less than 0.10 per m^2.

Figure 7-2. Site-average capture time as a function of adult-sized snails per m^2. Prediction line (solid line) and associated upper (UCL) and lower (LCL) 95% confidence limits (dashed lines) were determined from non-linear analysis. Stars represent data points from two sites in WCA3A in 1987 (Bennetts et al. 1988). Figure adapted from Darby et al. (2012); used by permission from the University of California Press: The Condor, The effects of prey density on capture times and foraging bout success in adult snail kites, 114(4):755-763, P.C. Darby, I. Fujisaki, and D.J. Mellow.

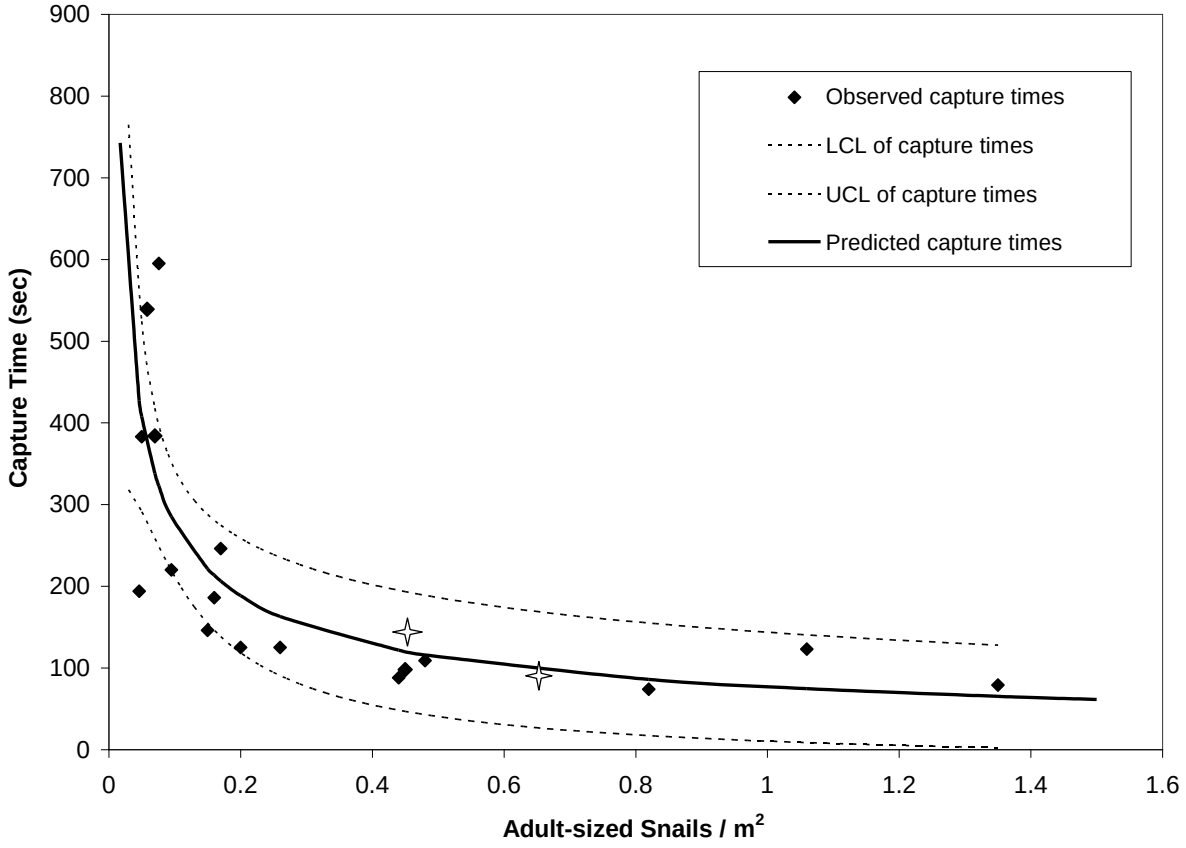
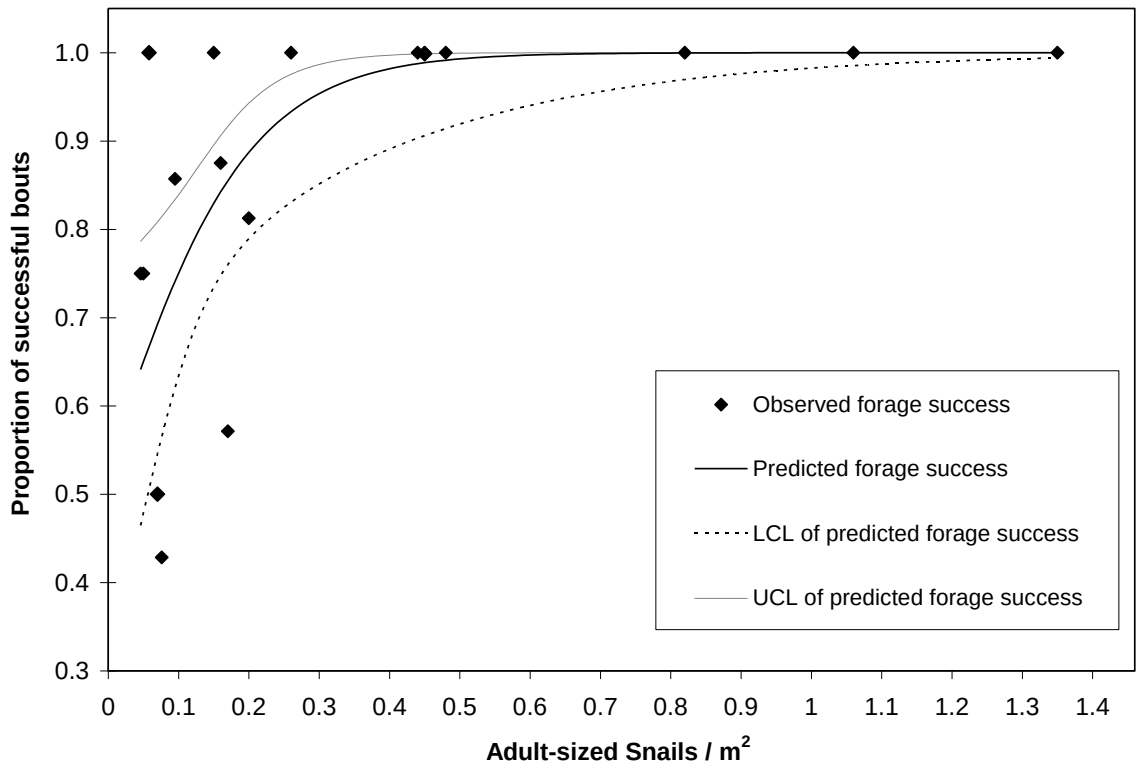


Figure 7-3. The proportion of successful foraging bouts by snail kites as a function of adult-sized snails per m^2. Prediction line (solid line) and associated upper and lower 95% confidence limits (dashed lines, UCL and LCL, respectively) were determined by logistic regression. Figure adapted from Darby et al. (2012); used by permission from the University of California Press: The Condor, The effects of prey density on capture times and foraging bout success in adult snail kites, 114(4):755-763, P.C. Darby, I. Fujisaki, and D.J. Mellow.



Darby et al. (2012) suggested that snail kites may forage in low density sites in the absence of better options, although the aforementioned 0.14 snails per m^2 minimum threshold approximates the point below which capture times significantly increased and foraging bout success decreased. Darby et al. (2012) presented the concept of an expected harvest rate applied to snail kite foraging. Since kites have little to no information on prey availability prior to foraging for apple snails, they assess habitat patch profitability via the process of foraging. Adult snail kites have prior experience foraging in many wetlands throughout their range, including sites with high prey encounter rates and capture times < 75 seconds (Bennett and Kitchens 2000). Snail kites likely use prior foraging experience with short capture times to assess the relative quality of a current forage patch, as described for other birds foraging on inconspicuous prey (van Gils et al. 2003).

As noted in Darby et al. (2012), the exponential increase in capture times (and associated energy costs) while course hunting where snail densities fall below ~0.1-0.2 snails per m^2 has implications for snail kite conservation in Florida. Low foraging profitability reduces the number of nest attempts by snail kites, and causes kites to abandon active nests (Beissinger and Snyder 1987). Poor recruitment was associated with the > 50% decline in the Florida snail kite population documented since 2000 (Martin et al. 2007a). From 2000-2005, the number of snail kites near fledging age that were banded (< 50 in some years) during annual range-wide surveys dropped by 70% compared to the 1990s (Martin et al. 2007a). From 2004-2007, there were fewer than 0.1 adult-sized apple snails per m^2 in most sites sampled in WCA3A and other federally-designated critical habitats (WCA2B, WCA3B, LOKEE; Darby 2006, Darby et al. 2009). In contrast, Bennetts et al. (1988) found more than 200 nests and 170 fledging snail kites in WCA3A in 1987, and in their two sites sampled found > 0.4 snails per m^2. Time energy assessments (e.g., Cattau et al. 2010) and snail monitoring data indicate that > 300-sec prey capture times and/or low snail densities could serve as triggers for management actions to improve conditions in support of higher apple snail densities. For example, water management can improve conditions for: apple snail recruitment (Turner 1996, Darby et al. 2008, Darby et al. 2009), plant communities that support higher snail densities (Darby 2006, Karunaratne et al. 2006), and increased prey availability to kites (Sykes et al. 1995, Bennetts et al. 2006).

CALORIE BALANCE AND APPLE SNAIL CONSUMPTION RATES

Optimal foraging theory suggests that animals will forage so as to maximize their energy gain per unit of time (calories gained minus the costs of foraging), and will leave an area if unprofitable to

find a more profitable one (MacArthur and Pianka 1966). In this section, we address the calorie gain from consuming snails and the associated costs of foraging and other daily activities. Estimates of the number of apple snails consumed per day (which may be helpful in future efforts to estimate carrying capacity of a wetland) can be approximated, but, based on the literature, no one has reported this directly.

Foraging metrics have been linked to snail kite energy balance models and reproductive success (Beissinger 1983, Beissinger and Snyder 1987, Cattau et al. 2010). Cattau et al. (2010) reported time-activity data on foraging snails kites, including locations (LKISS, WCA3A) and times (spring 2006-2007) that overlapped with locations and times when Darby et al. (2012) also recorded capture times. Cattau et al. (2010) estimated that snail kite energy consumption was 167 kcal/day, with 3.93 kcal per snail, or, by calculations from Darby et al. (2012), a total of 42 native Florida apple snails consumed per day. Given 42 snails consumed per day, Darby et al. (2012) concluded that kites foraging in high prey density sites would spend 52.5 min per day in flight (42 snails at 75 seconds each) compared to 175 min (250 sec per snail) or 350 min (500 sec per snail), the approximate range of foraging times and snail densities reported in Darby et al. (2012; also see Figure 7-2). Based on Beissinger's (1983) study of snail kites in Guyana, South America, flight time (79 min per day) costs 26.6 kcal per day (using energy cost equations in Koplin et al. 1980), or 0.34 kcal per min for course hunting. Beissinger (1983) estimated that the energetic costs of foraging in his low prey density areas were 59.5-119 kcal per day, as compared to 18 kcal per day in high prey density sites. The differences observed by Beissinger (1983) were explained by kites engaging in more perch hunting (less flight time) in high density sites compared to low snail density sites. Given reported daily total energy costs of 85.7 kcal (Beissinger 1983), 119 kcal (Cattau et al. 2010), and 110-173 kcal (includes snail kites in Florida feeding nestlings; Beissinger and Snyder 1987), the additional costs of foraging (i.e., increased flight time) in low prey density sites could more than double a snail kite's daily energy expenditure (Darby et al. 2012).

Beissinger (1983) estimated that daily calorie intake for snail kites foraging on *Pomacea doliodes* in Guyana was 104.2 kcal/day per kite. Calorie content of soft tissues in *P. doliodes* (similar in size to *P. paludosa* in Florida) was estimated as 6.39 kcal/snail (based on calorie and wet weight data reported). The estimated number of snails consumed per day (assuming 12 hrs of daylight) would be 16. However, note that about 50% of Guyana kites' foraging was perch hunting (Beissinger 1983), so comparisons to Florida kites and their consumption rates must be made with this caveat in mind.

Sykes (1987b) reported that snail kites captured snails at a rate of 1.7-3.4 per hour. Although Sykes (1987b) suggested foraging rates of individual kites may decrease slightly during mid-day, Cattau et al. (2010), who included a more detailed time-energy budget analysis, found no significant effect of time of day on capture rates. Based on Sykes (1987b), assuming approximately 12 hrs of daylight per day, kites were capturing from 20-40 apple snails/day (close to estimates of 42/day, see above). Of course, snail size may affect the total caloric needs, but additional detailed studies would be required to compare total amounts of snail tissue consumed per day.

THE INFLUENCE OF NON-NATIVE SNAILS ON SNAIL KITE DISTRIBUTION

In approximately 2001, the invasive, non-native apple snail *Pomacea insularum* became established in wetlands occupied by snail kites (Darby 2006). [Note that this snail was incorrectly identified as *P. canaliculata* until the Rawlings et al. (2007) study]. Kites were observed foraging on *P. insularum* in 2004 (Darby et al. 2007) in Goblet's Cove on LTOHO. Since that time, the exotic snail has spread throughout the entirety of LTOHO. Although snail kites drop the largest specimens (shells > 70 mm) at high rates, overall, kites have been successfully foraging and surviving on these exotic snails. Note that native snail densities on LTOHO were very low prior to the establishment of the exotic species (see Darby 2006).

Cattau et al. (2010) reported that juvenile snail kites struggled to capture and consume exotic snails of the largest size classes. The authors also expressed concerns over the energetic balance of juvenile kites and reported lower calorie content per gram of snail tissue compared to the native snail (Cattau et al. 2010). However, the exotic snails hatch out at ~1-2 mm in size, and must pass through size classes most suitable for kite foraging (approximately 20-50 mm according to Sykes 1987b). Consequently, snail kites have survived and successfully nested (e.g., Reichert et al. 2011b) with the exotic snails as their primary, or even only, source of food. In the last several years, more active snail kite nests have been found on LTOHO than on the other lakes/wetlands in the annual snail kite monitoring program (i.e., in 2005 and 2007-2011; see Table 3-1).

As the exotic snail has invaded more wetlands in the past several years, foraging and nesting snail kites have responded by shifting their distribution. In some cases (e.g., LOKEE), the native snail had largely disappeared, and now the exotic apple snail is the dominant apple snail species (Darby 2006, Darby 2012, unpublished data). [There is no evidence that the exotic snail displaced the native directly through competition or any other means]. Wetlands dominated by the exotic snails that have attracted snail kites in recent years include LTOHO, East LTOHO, Lake Runnymeade, LOKEE, and

STA-5 (periodic Snail Kite updates provided by Z. Welch, FFWCC). Kites frequently forage for and capture these snails in hydrilla-dominated habitat (Darby and field crew, pers. obs.; Reichert et al. 2011b), at least in the KCOL. Most sites appear to support exotic snail densities similar to what has typically been found for native snails, approximately 0.2 to 1.0 snail/m^2 (Darby 2006, Darby unpublished data). However, Darby and Therrien (unpublished data) recently reported densities of exotic snails > 20 mm in shell width over 5/m^2 where kites were foraging on LOKEE (and in the vicinity of active nests). On LOKEE in 2012, only exotic snails were available where kites were observed foraging. Since 2010, the exotic snail has also been found in WCA3A immediately north of the Tamiami Trail, and kites forage on both native and exotic snails in the *Eleocharis* and *Panicum* habitats characteristic of southern WCA3A (P. Darby 2011-2012, unpublished data). The exotic snails available to foraging kites on WCA3A and LOKEE had an average shell width of 29 mm (±9mm SD) (estimates based on preliminary data; Darby and Therrien, unpublished). Therefore, handling issues reported earlier for large exotic snails found on LTOHO (Darby et al. 2007, Cattau et al. 2010) were not evident for snail kites foraging on exotic snails in LOKEE and WCA3A in 2012.

Some view the establishment of the exotic apple snail as a benefit to snail kites, especially in light of low native snail densities in wetlands formerly important to kites. However, potential problems, such as parasites (Rawlings et al. 2007) have yet to be explored. In addition, the fact that native apple snail populations have declined in many areas (including areas with no known occurrence of exotic apple snails) suggests there may be potential perturbations to many Florida wetland systems in general. Diminishing native apple snail populations may be an indication of wide-spread habitat degradations that likely affect a multitude of native wetland species.

CHAPTER 8: TOOLS FOR SIMULATING SNAIL KITE AND APPLE SNAIL POPULATION CHANGE AND ESTIMATING HABITAT SUITABILITY

INTRODUCTION

The snail kite population depends on a network of wetland units from Orlando to Miami. These wetlands support a range of different plant communities, have different substrates (peat vs. sand) and underlying water chemistries (low to high nutrient, low to high calcium levels), and are subject to different degrees of water and habitat management. All of these environmental parameters influence snail kites (Chapter 3) and apple snails (Chapter 4). Snail densities and hydrologic and habitat conditions vary temporally, and snail kites respond to these changes (Chapters 5-7). All of these environmental parameters also fluctuate at spatial and temporal scales that are difficult to predict (Mooij et al. 2007). Although the kite population has been monitored since 1969 (Chapter 2), the large combination of conditions that may influence kite demography over their entire range cannot realistically be captured with empirical data. Computer models offer an opportunity to represent snail kite demography and habitat conditions mathematically, and model output can be compared to existing empirical data to validate the model and identify information gaps that warrant more investigation. Computer simulations of hydrologic conditions (input for the model) provide an opportunity to evaluate the impact of different water management scenarios on snail kites. Here we describe models developed (or being developed) for simulating kite and snail populations as they respond to environmental variation, and we describe a tool for assessing spatial distribution of suitable water depths for snail kite nesting that could also be applied to several other aspects of kite and snail ecology.

SNAIL KITE POPULATION MODELS

Mooij et al. (2002) developed an individual-based, spatially explicit simulation model that projected snail kite population changes under varying hydrologic scenarios. The model was eventually called *Everkite*, as reported in Mooij et al. (2007). Both temporal and spatial patterns of kite numbers can be predicted from *Everkite*. The model can be run so as to capture environmental stochasticity (*Everkite* version 3.01, see Mooij et al. 2002) or at a finer scale to reflect more details on what influences kite demography (based on an extensive empirical data set, see Mooij et al. 2007). Both models include spatially explicit details that represent 14 major wetland units used by nesting kites, as well as a general "peripheral" habitat for non-nesting habitats (see Valentine-Darby et al. 1998). The model is structured as follows (from Mooij et al. 2007):

1) Each kite is individually tracked in the model with variables representing gender, age, spatial location, and reproductive status.
2) The 14 main wetland areas were assumed to have relatively uniform conditions within each wetland; the peripheral areas as a group were assumed to represent habitat of relatively poor quality (supports foraging but not nesting).
3) Input for hydrologic condition was at the scale of a wetland unit; main parameters of interest were frequency of global droughts (range-wide), frequency of local droughts, and time interval between droughts.
4) Each wetland unit can have changes in hydrology and these changes are assumed to directly affect snail abundance. Water levels are directly translated to habitat quality; decreasing water levels translate to lower snail abundance where kites tend to move away).
5) Kite movements reflect higher probability of moving to close-by wetlands rather than distant wetlands (see Chapter 5, Movements).
6) The model includes aging, reproduction (several aspects including nest initiation and success), movement, and mortality as they influence total kite numbers and wetland-specific occupancy.
7) The model produces the number of kites in each wetland on a weekly basis.

Everkite was first used to study the influence of spatial extent and mobility on snail kite population dynamics in relation to hydrologic conditions in the kite's range (Mooij et al. 2002). The emphasis so far has been to evaluate the impacts of drought condition on kites. Results of the model simulations were that: 1) high drought frequencies led to lower numbers of kites, 2) prolonged periods of inundation (resulting in habitat degradation) led to lower numbers of kites, and 3) when spatial correlation between droughts was low, there was little variability in kites numbers, but the opposite was also true (Mooij et al. 2002).

Mooij et al. (2007) used a version of the *Everkite* model (a deterministic matrix model version; *Everkite* 4.01 [different from that used in 2002]) to study the effects of temporal variation in water levels on the population growth rate of the snail kite in 15 of the major wetland units in Florida (plus one peripheral habitat category). Their simulations varied three aspects of water levels— drought frequency, drought duration, and drought timing within the year. Due to potential negative effects of both drought conditions and extended periods of time without droughts, the authors hypothesized that an intermediate frequency of droughts would provide optimal conditions for the snail kite population

over the long-term (fitting the idea of the "intermediate disturbance" hypothesis, in which the highest diversity in a community is maintained at intermediate levels of disturbance [Connell 1978]; also see Chapter 6 with regards to snail predation and hydrology).

Empirical information used in the model was from the demography and movement study of snail kites (primarily Bennetts and Kitchens 1997a, but also see Chapters 3 and 5). For the 2007 work, model input included historical weekly water levels for each wetland for 1965-1996 (Mooij et al. 2007). Water level states in the model included *high*, *low*, *drought*, and *lag* (which referred to a year following a drought). The model was used to simulate four scenarios, the first two of which related to changes in the amplitude of water level fluctuations, and the second two of which related to within-season changes in the timing of water levels and drought durations. Modification of the amplitude of water level changes (while keeping mean annual water levels constant) had a dramatic effect on modeled population growth. They found that the smallest amplitude fluctuations led to the greatest effect; this was because dry down frequency decreased and led to long-term adverse impacts on wetland vegetation/kite habitat. Population growth was also negatively affected by increases in amplitude, due to an increase in the frequency of droughts. Manipulation of drought duration in the model also led to effects on the population growth rate. This observed effect was related to greater impacts to kite survival and reproduction as drought duration was increased. The authors pointed out limitations in the model since parameterization did not yet include 1) the frequency of flooding (high water), which could adversely affect apple snail recruitment (citing Darby et al. 2005), kite nesting, and/or foraging habitats, or 2) the effect of prolonged drought on apple snails. The authors emphasized that their modeling work showed the importance of considering the frequency, duration, and timing of dry downs, as discussed in Bennetts and Kitchens (1997b) and Bennetts et al. (1998a), and later by Darby et al. (2008) and Martin et al. (2008).

Gaines et al. (2008) described the latest version (5.05) of *Everkite*, which is a grid-based system that reflects water levels at a 2-mile x 2-mile (3.2-km x 3.2-km) scale in order to accommodate data available from the South Florida Water Management Model (SFWMM; available at http://www.sfwmd.gov/portal/page/portal/xweb%20-%20release%202/south%20florida%20water%20management%20model). Since *Everkite* was designed to model response of kites to water stage, these depth data from SFWMM were converted to stage by adding the ground elevation estimate for each 2 x 2 grid cell (i.e., stage in meters or feet above mean sea level = depth plus ground elevation). The model continues to consider hydrologic condition at the scale of a wetland unit in keeping with the original spatial scale of interest in *Everkite*

(see Mooij et al. 2002). The spatial extent of *Everkite* 5.05 remains the same as described above (15 main wetland areas plus grouped peripheral locations). In addition, more recent biological information was incorporated (e.g., negative effects of high water on kites due to habitat effects [including snail availability and loss of woody nest substrates]. Gaines et al. (2008) report the changes made to advance the *Everkite* model, but did not report simulated hydrologic scenarios and how the modeled kite population responded to them.

APPLE SNAIL POPULATION MODEL

A spatially explicit apple snail model is currently under development, with plans for the model output to be linked to *Everkite* (Darby et al. 2010). [All information in this section is from Darby et al. 2010]. Because snail kite distribution depends largely on finding sufficient apple snail densities to support their foraging needs, understanding how hydrology impacts snails increases the understanding of how hydrology impacts kites. The apple snail model can be used to describe the response of apple snail populations to changes in seasonal water depths and longer-term hydrologic regimes.

Environmental input data for the model are daily water depths and air temperatures because, based on the available data, these parameters have the greatest influence on snail egg cluster production (Darby et al. 2010). Spatially explicit depth data come from the Everglades Depth Estimation Network (EDEN). The spatial resolution matches that of EDEN, 400 m x 400 m. Temperature data were interpolated from data available on DBHYDRO (SFWMD) from several weather stations to represent WCA3A. The intended use of the model is to create "what–if" hydrologic scenarios using an EDEN data framework, an effort that was initiated in Summer 2011. For example, the model will be used to simulate drying events of different durations or at different return intervals to predict the response of snail populations to specific water management plans or scenarios.

The apple snail model is size-structured and has a 1-day time step. Model parameterization was based on empirical data and includes (per Darby et al. 2010):

1) size-class dependent survival rates in dry down and flooded conditions (Darby et al. 2008).
2) temperature/seasonal-based patterns of egg cluster production (Hanning 1979, Darby et al. 2008).

3) clutch size (Hurdle 1974, Hanning 1979).
4) the effects of water depth on egg cluster production (Darby et al. 2009).
5) incubation and hatching rates (Hanning 1979).
6) the effects of submersion on egg survival (Turner 1998).
7) hatchling growth rates (Hanning 1979, Glass and Darby 2009).

Future versions of the model will incorporate additional environmental effects, such as dominant emergent vegetation and submerged aquatic species. Remotely sensed data are becoming more available and might be useful for this purpose (see Gann et al. 2012). Although the status of the model and/or data available presently precludes it, information on the density of aquatic predators, snail kites, and apple snail competitors would be highly desirable for inclusion in the future. Model output can be viewed in graphical form (specified locations indicated by user) or as spatial overlays using color coded maps via EVERVIEW (http://pubs.usgs.gov/fs/2010/3046/pdf/FS10-3046.pdf).

During model development, graphical output from specific locations created by running iterations of the model were compared to empirical data from field studies of snail density and egg cluster production in WCA3A. The field data were collected from 2002 and 2007 (Darby et al. 2005, Darby et al. 2006, Darby et al. 2009), and these data overlap in time with currently available EDEN depth data. This provided a way to validate model output and identify potential problems with model parameterization. Model output evaluated in this validation process included total snail abundance (converted to density, based on 400 m x 400 m cell, to compare to empirical density data), adult-sized snail abundance, and total egg cluster production. The goal of modeling team members (which includes D. DeAngelis and S. Romanach, USGS, J. Bridevaux, USGS contractor, and P. Darby, UWF) is to publish the first validated iteration of the model, including some simulated hydrologic scenarios (e.g., dry downs of varying duration), in 2013 (P. Darby, pers. comm.).

SNAIL KITE NESTING DEPTH PREFERENCE TOOL- EVERGLADES

Lo Galbo et al. (2010) developed a tool to simulate the suitability of water depths within the nesting range of snail kites in WCA1, WCA2, WCA3, and ENP during the nesting season (January-July). The model, or *Everglade Kite Nesting Depth Preference Tool*, calculates the number of days during the nesting season that water depths are within the range of 20-80 cm. This depth range was reported by Bennetts et al. (1988) for 94% of the nests (at the time of nest initiation) recorded during their two-year nesting study in WCA3A. The nesting depth preference tool has been used by ENP to

examine the effects of historical changes and anticipated effects of CERP restoration projects on the snail kite (Lo Galbo et al. 2010). Hydrologic simulations were conducted on current conditions, the estimated pre-drainage Everglades habitat, and future conditions under CERP. The simulations used data from an average rainfall year (1992). [Note that what constitutes "average" depends on conditions defined by researchers, see Appendix C]. Simulation results indicated improved nesting conditions for kites in the pre-drainage Everglades compared to existing or future conditions. However, results also predicted that, overall, CERP implementation would improve snail kite nesting conditions in the three WCAs and ENP and connectivity between nesting habitats. Darby and Wight (2011) generated similar output by analyzing the number of days at certain depth ranges as an indication of suitable hydrologic conditions to support apple snail egg cluster production (see below).

APPLE SNAIL OVIPOSITION-HYDROLOGY ASSESSMENT TOOL

Darby and Wight (2011) studied the seasonal water depth in three wetlands, WCA3A, WCA2B, and LOKEE, and related these depths to those estimated to be suitable or not suitable for apple snail egg cluster production. Although not developed as an assessment tool, per se, their approach was very similar to that taken by Lo Galbo et al. (2010) for snail kite nesting. What we describe here as an oviposition-hydrology assessment tool was derived from Darby and Wight (2011) via a project funded by USFWS (Grant Agreement No. 401815G045). A primary focus of their approach was coming up with metrics that reflect favorable water depths that support apple snail egg cluster production. They generated hypotheses that may warrant further investigation, some of which are described below and in Chapter 11.

Darby and Wight (2011) used a combination of stage data (DBHYDRO) and field-based ground level estimates to estimate water depths. At this point in their assessment, they intentionally focused on sampling sites for which some apple snail density and egg cluster data existed. Here we present their findings from WCA3A, since the vast majority of available data on apple snails in the Everglades comes from WCA3A. Daily water depths were estimated by subtracting ground level estimates from daily stages (see Appendix A.I.C. in Darby et al. 2009). They compared their estimates from their sampling sites to those reported by EDEN (which represent a larger scale and more habitat types), and found that their estimates were exactly the same or within ± 5 cm (Darby and Wight 2011). Darby and Wight (2011) characterized seasonal water depths from 1980-2006. They emphasized that their assessment of hydrologic conditions pertained only to the sampling sites (Figure 8-1); they did not extrapolate to the entire wetland unit. However, this approach could be applied to

all of WCA3A and other wetlands for which spatially explicit EDEN depth data are currently available.

As described in Chapter 4, water depths at a lower limit of 10 cm and an upper limit of approximately 40-60 cm are most suitable for apple snail egg production. In order to develop Darby and Wight's (2011) work into an oviposition-hydrology assessment tool, this range of depths should be validated through further study. Depths for the months of peak snail egg production, March-June, were distinguished from other months for egg production, July-October, for the assessment. By examining the number of days with depths of 10-40 cm during the peak of snail egg production, Darby and Wight (2011) identified years that were favorable or unfavorable for apple snail recruitment along a depth gradient in WCA3A (Table 8-1). [Whether the upper limit should be 40, 50 or 60 cm is debatable, but 40 cm was chosen for this exercise)]. They also considered scenarios where conditions in March-June were unfavorable, but improved in summer (Table 8-2) when some egg production typically occurs (Darby et al. 2008). For example, Darby (UWF, pers. obs.) observed fresh egg production immediately after rains that resulted in flooding of dry marsh in WCA1 in June 2001. They also looked at available snail density information (Bennetts et al. 1988, several reports and publications from Darby et al.) as an indicator of the suitability of current and prior year water depths.

Darby and Wight (2011) generated tables showing the numbers of days in the 10-40 cm depth range, a March-June table (8-1) and a July-October table (8-2). In sites and years with no days at 10 cm or above in a given month, they shaded table cells yellow to show conditions too dry to support egg cluster production. In sites with no days at or below 40 cm, they shaded table cells blue to show depths above what has been estimated to be suitable for egg cluster production. The tables show that large areas like WCA3A, with significant topographic variation, may have portions too wet or too dry to support egg cluster production, while other areas within the wetland have 10-40 cm depths. For example, 1981 and 1982 each supported ~50-60 days of 10-40 cm water depths in southern WCA3A sites (Table 8-1), but water depths were < 10 cm for much of the peak breeding season in areas further north (Table 8-1).

Darby and Wight (2011) also illustrated some scenarios where despite relatively unsuitable depths during the March-June period, conditions can change in summer such that depths become favorable for egg cluster production. Apple snail egg production typically peaks between March and June (Darby et al. 2008), unless dry down conditions dominate this time period (O'Hare 2011). In

Figure 8-1. Apple snail sampling sites (gray circles; from north to south, 18, 17, 11, 3, 16, and 14) used as a reference for hydrologic conditions in WCA3A. Ground elevations (in meters above sea level) appear next to each site. Latitudes (numbers lined up with dashed lines) provided for reference; latitudes and longitudes for each site from Darby et al. (2009). Map adapted from Darby et al. (2009) and Darby and Wight (2011).

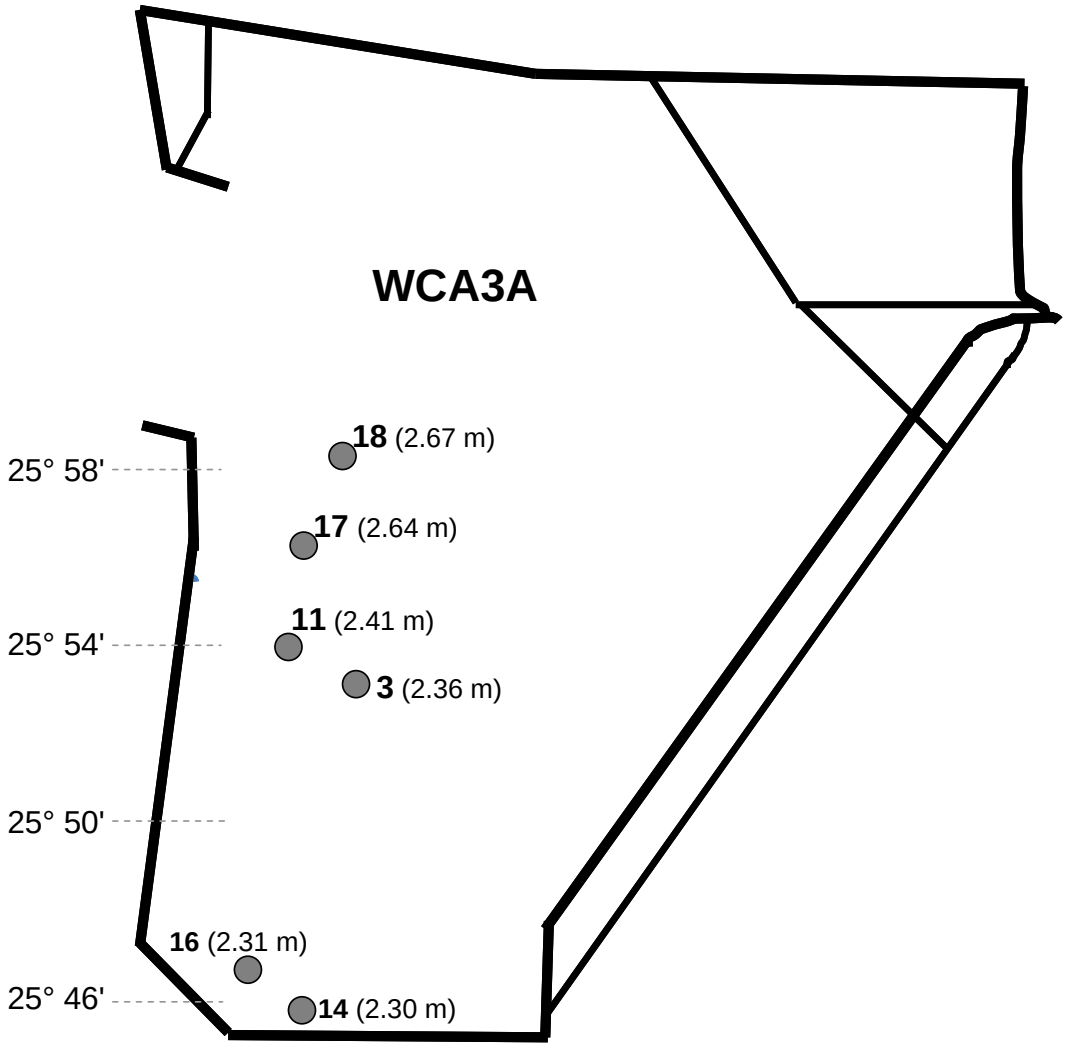


Table 8-1. Number of days from March 1 to June 30 with water depths from 10-40 cm in 9 sites in WCA3A from 1980-2006. Sites are listed from north to south (see Figure 8-1 for representative site locations). Yellow = too dry (≤ 10 days with depths above 10 cm), Blue = too wet (≤ 10 days with depths below 40 cm). From Darby and Wight (2011), used by permission.

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Site 18	94	7	8	62	108	0	113	70	60	0	0
Site 17	72	24	7	65	112	0	111	66	77	0	0
Site 11	0	44	20	74	122	0	51	65	84	0	0
Site 3	0	53	32	62	119	0	41	58	59	13	0
Site 12	0	64	56	34	60	4	25	48	49	28	0
Site 16	0	62	53	38	71	2	29	53	51	26	0
Site 10	0	62	53	38	71	2	29	53	51	26	0
Site 13	0	65	58	32	56	6	20	45	47	29	0
Site 14	0	64	56	34	60	4	25	48	49	28	0

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999
Site 18	14	51	10	100	58	116	112	62	112
Site 17	18	71	6	92	52	113	108	58	106
Site 11	26	101	6	40	29	52	50	53	88
Site 3	48	102	0	17	0	22	18	47	79
Site 12	64	91	0	0	0	0	0	30	68
Site 16	61	95	0	0	0	0	2	37	70
Site 10	61	95	0	0	0	0	2	37	70
Site 13	64	87	0	0	0	0	0	25	66
Site 14	64	91	0	0	0	0	0	30	68

Year	2000	2001	2002	2003	2004	2005	2006
Site 18	114	52	61	101	83	111	58
Site 17	122	74	65	92	108	108	62
Site 11	115	80	87	50	102	67	93
Site 3	85	101	72	38	90	49	86
Site 12	66	120	54	0	71	28	75
Site 16	68	118	58	1	76	32	76
Site 10	68	118	58	1	76	32	76
Site 13	60	122	51	0	66	24	73
Site 14	66	120	54	0	71	28	75

Table 8-2. Number of days from July 1 to October 31 with water depths from 10-40 cm in 9 sites in WCA3A from 1980-2006. Sites are listed from north to south (see Figure 8-1 for representative site locations). Yellow = too dry (≤ 10 days with depths above 10 cm), Blue = too wet (≤ 10 days with depths below 40 cm). From Darby and Wight (2011), used by permission.

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Site 18	72	26	0	64	116	29	3	38	37	0	29
Site 17	54	27	0	63	106	17	1	41	28	0	91
Site 11	0	4	0	39	73	14	0	104	10	63	97
Site 3	0	3	0	0	15	13	0	100	0	63	98
Site 12	0	0	0	0	0	12	0	89	0	53	105
Site 16	0	1	0	0	0	13	0	91	0	56	104
Site 10	0	1	0	0	0	13	0	91	0	56	104
Site 13	0	0	0	0	0	17	0	87	0	50	118
Site 14	0	0	0	0	0	12	0	89	0	53	105

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999
Site 18	25	11	52	32	0	0	0	79	0
Site 17	25	4	30	24	0	0	0	78	0
Site 11	3	0	7	14	0	0	0	35	0
Site 3	1	0	0	0	0	0	0	20	0
Site 12	0	0	0	0	0	0	0	16	0
Site 16	0	0	0	0	0	0	0	17	0
Site 10	0	0	0	0	0	0	0	17	0
Site 13	0	0	0	0	0	0	0	16	0
Site 14	0	0	0	0	0	0	0	16	0

Year	2000	2001	2002	2003	2004	2005	2006
Site 18	94	33	0	0	42	0	59
Site 17	90	33	0	0	52	0	59
Site 11	36	28	0	0	43	0	19
Site 3	31	22	0	0	33	0	12
Site 12	26	20	0	0	31	0	9
Site 16	27	20	0	0	32	0	11
Site 10	27	20	0	0	32	0	11
Site 13	22	19	0	0	31	0	8
Site 14	26	20	0	0	31	0	9

this case, spring-summer rains that subsequently raise water depths to 10-40 cm may offer an opportunity for snails to recover a portion of the reproductive potential lost in the March-June season. For example, in 1990 in WCA3A, dry conditions prevailed in March-June (Table 8-1). Since snails do not mate or reproduce in dry conditions, no eggs would be produced during this time. Water levels then rose in July 1990, resulting in 29-118 days (depending on the latitude, north to south) of water depths in the 10-40 cm range (Table 8-2). Any egg production under this scenario would come from adult snails that had survived the dry down conditions. Apple snails have the capacity to recover from a drying event and lay eggs within days of rising water levels (P. Darby, UWF, pers. obs., WCA1 in 2001), although to what degree their potential fecundity is realized following a period of aestivation has not been established.

Darby and Wight (2011) provide another example of conditions improving during the July-October period. In this scenario a relatively wet March-June period, with depths > 40 cm, may be followed by receding waters in summer. This was true for Sites 17 and 18 in WCA3A in 1993 (Tables 8-1, 8-2), and in portions of WCA2B in 1993 (data not shown). Although not an "optimal" scenario for snail recruitment, this could allow for population persistence and a rapid recovery when conditions improve in subsequent years. These scenarios form the bases of hypotheses yet to be tested.

Darby and Wight (2011) described the worst-case scenario for egg production as when depths exceed 40 cm in March-June, and then water levels increase in summer and fall (e.g., WCA3A in 1994-1995 and 2003; see Tables 8-1, 8-2). The negative impacts of these relatively high water conditions were detailed in Chapter 6.

Hydrologic and habitat assessment tools for both apple snails and snail kites require additional validation. This may include additional analyses of existing data and collecting additional data from field studies. The use of EDEN data to characterize spatially explicit conditions in critical wetland units, and spatial distribution information for snail kites and apple snails in those wetlands may be a promising approach.

CHAPTER 9: SYNTHESIS, SUMMARY AND CONCLUSIONS FROM THE LITERATURE REVIEW

Up to this point in the document, we have reviewed the existing literature on apple snails and snail kites from publications and project reports. The conclusions and interpretations in those chapters came largely from the original publication/report authors. In this chapter, we discuss some of the main points from the literature and point out connections and information needs that have not been described elsewhere. We also include some points made by reviewers, especially where there appear to be some different perspectives on the snail kite and apple snail literature.

The subspecies of snail kite found in Florida, *Rostrhamus sociabilis plumbeus*, was listed as an endangered species in 1967[1]. Since 1969, the population has been monitored annually. Over 100 journal articles, reports, and book chapters have described the snail kite's dietary specialization, foraging and nesting habitats, dependence on wetlands that experience hydrologic fluctuations, the influence of periodic drying events, and its use of wetland landscapes with a shifting mosaic of heterogeneous plant communities. Long-term sustainability of the snail kite population depends on its ability to adjust to "boom or bust" habitat conditions in some years. For example, in years with limited prey availability due to dry conditions, kites may not attempt to nest; however, in years with abundant prey and desirable nesting conditions, kites may successfully fledge young from more than one nest (see Chapter 3). Nomadic tendencies and an ability to utilize an extensive assemblage of major wetland units and smaller peripheral ones from Orlando to ENP is a fundamental component of that strategy. Snail kite dependence on *Pomacea* snails, how kites capture and handle their prey, the types of habitats in which kites forage, and those they avoid, have been described by several observers in numerous reports. However, the prey itself has received much less attention. Fewer than about 5% of publications on snail kites include a direct measure of apple snail abundance; consequently, despite over 40 years of monitoring and research on kites, significant information gaps exist on fundamental aspects of how prey density and availability influences snail kite demography.

What we know about snail kites was influenced by the protocols used to study them in particular hydrologic eras. For example, the only large-scale telemetry study, conducted in 1992-1995, occurred when wetlands critical to kites (e.g., WCA3A and LOKEE) had relatively high water. Therefore, we still have limited data on how individuals respond to receding water depths and the

[1] In general, we do not include literature citations here; see more details and citations in Chapters 1-8 and appendices referred to throughout this chapter.

full extent of peripheral habitat utilization when critical wetlands become dry (also see comments by R. Bennetts, who conducted the 1992-1995 telemetry study, in Appendix B). Until approximately 2000, we did not have a reliable, validated, and cost effective method to estimate apple snail densities, and lack of snail data likely influenced the interpretation of behavior and demographic patterns of snail kites. Numerous papers make associations between kite demography and hydrologic and habitat conditions. However, no paper or report has included analyses of the relative magnitude of the influence of prey density on kite demography as compared to other hydrologic and habitat metrics. The relative importance of snail density data to our understanding of kite demography has been questioned, especially in light of the additional expense and effort of collecting that data (see comments by Z. Welch in Appendix B). Assumptions that apple snails are unable to tolerate dry down conditions, and that long hydroperiods result in greater snail densities (without considering water depths), have been proven incorrect (Chapters 4 and 6). These assumptions about dry down intolerance, in particular, may have resulted in some incorrect conclusions about how snail kites respond to changes in their environment.

Data from the annual fall snail kite count, initiated in 1969 and ending in 1994, indicated the snail kite population generally increased over that time. Issues with observer effects and effort, and the influences of habitat type and water levels on the ability to detect kites (described previously) likely confounded those counts. However, Bennetts et al. (1999a) adjusted for some of the confounding factors and still estimated an overall population increase over the period. A mark-resighting study was initiated in 1992 in order to address some of the short-comings of the annual fall count. The annual breeding season survey now produces a “superpopulation” estimate for the snail kite population in Florida.

Although the historic decline in snail kites that led to their endangered status likely related to widespread wetland loss through drainage, the majority of the network of wetlands that existed when the kite was listed still exists today. Despite this, the snail kite population declined from over 3,000 to fewer than 1,000 birds in the last 13 years, as documented by the annual breeding season survey and superpopulation estimates. This recent decline cannot be blamed mainly on wetland loss (i.e., conversion/destruction), but rather on degraded habitat quality (Chapter 5), although direct measures of habitat quality are generally lacking. Conclusions regarding habitat degradation likely include an influence of decreased apple snail availability (as measured by snail density) in ecologically critical wetlands (Chapters 6 and 7). The result of apparent habitat degradation has been a decline in total kite nest numbers and number of young fledged in the 2000s compared to the 1990s, and, for the first

time since routine monitoring began, zero percent nest success in WCA3A. Historically (over the years monitored), WCA3A produced the majority of kite fledglings in the population. In 2005, 2007, and 2010, the small number of nests recorded in WCA3A all failed, and in 2001 and 2008 no nests were recorded. In recent years, the majority of snail kite recruitment has taken place on lakes where kites forage on exotic apple snails, many of which were captured from hydrilla-dominated habitat. The recent reappearance of snail kites nesting on LOKEE was also associated with the establishment and relatively high abundance of exotic snails where kites were observed foraging (see Chapter 7).

Since routine studies began, researchers have consistently characterized the snail kite as a long-lived species, with adult annual survival typically ~0.90 (Chapter 5). Population fluctuations reflect cyclical favorable and unfavorable wetland conditions that strongly influence adult fecundity and associated juvenile survival. Early estimates from demographic models based on the annual fall count indicated that the snail kite population could go up to 9.5 years with poor recruitment before the population declined by 50%. However, more recent observations (1998-2002) documented a 50% decline in approximately 4 years. This decline has been attributed to a combination of poor recruitment and a significant decline in adult kite survival during relatively dry years (Chapter 5).

Martin et al. (2006a) explored the influence of habitat fragmentation on the recent snail kite population decline, where fragmentation was quantified as degree of isolation of suitable wetland units from other suitable wetland units used by kites (see details in Chapter 5). They did not consider snail availability in the fragmentation analyses or interpretation of the analyses. During their period of study, as kite use declined in several critical wetlands, low apple snail densities were reported for these same wetlands (e.g., WCA3A, WCA3B, WCA2B and LOKEE; see Chapter 5, 6, 7). From our review of the snail kite and apple snail literature, we agree with Martin et al. (2006a) that there may be a problem with wetland network connectivity, but we believe it may be associated with snail availability (as indicated by snail density), and not necessarily other aspects of habitat quality (e.g., dominant plant community types). For example, LOKEE may be a critical wetland unit that links wetlands in the KCOL to the Everglades (WCAs and ENP) (see Bennetts and Kitchens 1997b); Darby (2006) found zero snails in four of six sites sampled (sites historically supporting kite nests) and densities of $\leq$0.06 snails/m^2 in the other two sites sampled in 2005. An increased effort to distinguish availability of suitable plant community types for snail kites from snail density (which can be low, despite the plant communities being suitable for kite foraging) is critical to understanding snail kite trends in wetland habitat use and connectivity of the habitat network.

More data on understanding how to support recovery of snail populations emerged as one of the critical recommendations for research in support of snail kite recovery (see Chapter 11, and reviews by C. Ruehl, Z. Welch, and others in Appendix B). Although the direct impacts of dry downs on snails have been documented, and are more straight-forward to understand (Darby et al. 2002, Darby et al. 2008), the influence (positive or negative) of relatively higher seasonal water depths remains less clear. Darby et al. (2005, 2009) associated depths of above approximately 40-60 cm with lower egg cluster production (both overall, but also on a per snail basis). These observations were consistent with prior reports of associations between depths and egg cluster production (see Chapter 6). However, these more recent associations have been made on relatively small amounts of data from discrete field studies, and a comprehensive analysis of all available data has yet to be completed (Darby, pers. comm.). Questions have been raised about the depth ranges that positively influence apple snail egg cluster production (see comments by Z. Welch, Appendix B), because snail densities have not recovered in WCA3A in recent years despite conditions, in some years, that appear suitable for egg cluster production. It may be that snail densities have reached critically low levels (which have been documented), such that egg production is low because there are so few snails mating and laying eggs (even under "ideal" conditions with all adults mating). There may also be a depensation effect, where individuals infrequently encounter others with which to mate, so the proportion of the population reproducing is lower compared to higher density populations (Stoner et al. 2012, also see comments by C. Ruehl, Appendix B). If the low density snail population is in a lag phase of population growth, it is unclear how long it will take for the population to recover to levels sufficiently high to support kite foraging and nesting. Clearly this is an area of research that requires more attention (see recommendations in Chapter 11).

Despite significant information gaps on the relative influence of apple snail densities, habitat condition, and hydrology on snail kites, we have sufficient information on these features of the kite environment to set some management targets in an adaptive management framework. Under this framework it is critical to monitor the response of kites and snails to prevailing hydrologic conditions, and make adjustments as necessary if observed trends differ significantly from predicted responses. Table 9-1 summarizes the trends and associations of snail kites in relation to snails, habitat, and hydrologic metrics; we emphasize nesting because recruitment into the kite population appears to be a major driver of population growth rates (Chapter 5). Management targets and recommendations

Table 9-1. Summary of trends and associations for snail kites.

TRENDS AND ASSOCIATIONS	SOURCE
Breeding Season	
Majority (89%) of nesting attempts in January-June.	Sykes et al. 1995
Breeding may last longer with favorable water depths and abundant food.	Beissinger 1988, Snyder et al. 1989a, Sykes et al. 1995
Nesting peak may occur several weeks later in northern habitats.	Toland 1994
Nesting Substrates	
Woody substrate used most often except on some lakes.	Sykes 1987a, Bennetts et al. 1988, Snyder et al. 1989a
Willow preferred when available.	Sykes 1987a, Bennetts et al. 1988
Cattail and bulrush (*Scirpus = Schoenoplectus*) frequently used on central Florida lakes.	Snyder et al. 1989a, Bennetts et al. 1994, Rodgers 1998,
Herbicide applications may damage herbaceous plants supporting kite nests.	Rodgers et al. 2001
Water Depths	
Nests built over water to avoid terrestrial predators.	Beissinger 1984, Sykes 1987a
Water depths beneath nests range from 10 to 115 cm (average 40-60 cm) in Everglades; 94% of over 200 nests initiated over water 20-80 cm deep in WCA3A in 1980s.	Sykes 1987a, Bennetts et al. 1988, Sykes et al. 1995, Dreitz et al. 1999
High water stages can lead to spatial shifts in nest distribution; kites avoided lower ground elevations (with water depths >1.5 m) in WCA3A, WCA2B, LOKEE.	Bennetts et al. 1988, Rodgers 1992, Bennetts et al. 2002
Recession rates that lead to depths under nests <20 cm before nestlings fledge, especially during the peak breeding season, may result in lower fledging / juvenile survival rates.	SEI 2007, Cattau et al. 2009
Foraging	
Snail densities less than ≈0.1-0.2/m^2 result in significantly longer capture times, decreased foraging bout success, and overall fewer kites foraging in the area.	Darby et al. 2006, Darby et al. 2012
Flooded marsh with low density emergent grasses and sedges best for foraging in Everglades; low density broad-leaved plants on lakes.	Kitchens et al. 2002, Bennetts et al. 2006, Darby 2006
Foraging habitat commonly in close proximity to nesting habitat.	Bennetts et al. 1988
Depths less than ≈10 cm make snails unavailable to kites.	Sykes 1979, Sykes et al. 1995, Kitchens et al. 2002, Darby et al. 2004
Nest Success/Failure	
Failures include those due to predation, nest collapse, adverse weather, and nest abandonment.	Beissinger 1986, Sykes 1987c, Bennetts et al. 1988 and 1994
Nest success may be reduced during low water events, and nesting may not occur during droughts/dry downs.	Sykes 1979, Beissinger 1986, Synder et al. 1989a, Dreitz et al. 2001 and 2002a, Beissinger and Snyder 2002
Table 9-1 Continued on next page.	

Nest success is higher in woody substrates; herbaceous plants are susceptible to collapse.	Sykes & Chandler 1974, Snyder et al. 1989a, Rodgers 1992
Habitat Network and Connectivity	
Kites leave wetlands with low water, and in severe droughts may move hundreds of miles to find flooded habitats. Movement probabilities between wetlands decrease with increased distance between wetlands.	Takekawa and Beissinger 1989, Bennetts and Kitchens 1997a, Martin et al. 2006a
During the breeding season, kites have a tendency to return to regions occupied in the previous year, and especially to their natal region.	Martin et al. 2007c
Some kite movements may be exploratory, providing information on potential refugia when drought conditions occur in the future.	Bennetts and Kitchens 2000

Table 9-2. Summary of trends and associations for native Florida apple snails.

TRENDS AND ASSOCIATIONS	SOURCE
Breeding Season	
February-October.	Odum 1957, Hanning 1979, Darby et al. 2008
Peaks April-June (occasionally in March), assuming no extreme high water or dry down influences (based on sampling in central Florida down to WCA3).	Odum 1957, Hanning 1979, Darby et al. 2008
Influenced by temperature, water depth, and (possibly) photoperiod.	Odum 1957, Hanning 1979, Darby et al. 2008
Water Level Effects on Egg Laying	
Receding water (down to ≈10 cm) appears to promote egg production.	Hanning 1979, Turner 1996
No movements, mating, or oviposition in depths less than ≈ 10 cm (including during drydowns).	Darby et al. 2008
Oviposition rates were lower in depths above ≈40-60 cm. Total per capita annual egg cluster production was higher with depths of 10-60 cm compared to depths above approximately 60 cm.	Gleason et al. 1975 (p. 86), Darby et al. 2005, Darby et al. 2009. Since this is based on a limited amount of data, additional research is recommended.
Submerged eggs fail to hatch.	Turner 1998
Egg Laying Substrates [a]	
Emergent vegetation with > 6 mm-diameter structures (e.g., stems, leaves) above water are needed to support ovipositon.	Hanning 1979, Turner 1996, Darby 2006
Majority of snail eggs found at ecotone. Most often used plants are sawgrass in graminoid marshes, and pickerelweed[b], bulrush (*Scirpus* spp.= *Schoenoplectus* spp.), and arrowhead species (*Sagittaria* spp.) on lakes.	Bennetts et al. 1988, Turner 1996, Darby et al. 1999
Table 9-2 Continued on next page.	

Temperature Trends	
21°C an approximate threshold below which snail activity declines dramatically; no activity in water <13°C.	Stevens et al. 2002
Incubation time decreases with increase in air temperature.	Hanning 1979 (pp. 70)
Hatching success increases with increase in air temperature.	Hanning 1979 (pp. 69)
Water Chemistry	
Higher snail densities and/or egg cluster counts associated with relatively higher pH and calcium levels.	Hurdle 1974, Gleason et al. 1975 (p. 85, 86), Darby et al. 2005 (p. 61)
Snail growth rates and shell crush weights significantly higher with Ca^{2+} > 28 mg/L and pH>7, compared to lower calcium and pH.	Glass and Darby 2009
Habitat / Vegetation	
Snail densities greater in low to moderate density Gulf Coast spikerush and maidencane marsh compared to white water-lily-dominated slough.	Karunaratne et al. 2006
Snail densities significantly lower in Gulf Coast spikerush with stem densities > 60 stems/0.5 m^2, compared to stem densities ≈30 /0.5 m^2.	Karunaratne et al. 2006
No or low numbers of snails in high density monoculture pickerelweed; no snails in floating mat pickerelweed.	Darby 2006, Z. Welch (FFWCC, pers. comm.)
Few or no snails in yellow cow-lily with unconsolidated organic substrates.	Darby et al. 2004
Tape grass (*Vallisneria*) supports highest snail densities in lakes and rivers (compared to other SAV available).	Bryan 1990, Darby 2006
Relatively few snails in water hyacinth (*Eichhornia*) and water lettuce (*Pistia*) mats.	Bryan 1990
Food sources include epiphytic periphyton and macrophytes.	Rich 1990, Sharfstein and Steinman 2001, Schuford et al. 2005
Hydrology	
Periodic drydowns support preferred vegetation (e.g. sawgrass and wet prairie species).	Ager & Kerce 1969, Gunderson 1994, Bennetts et al. 1998c, Sklar et al. 2002, Kitchens et al. 2002
Drydowns lasting 12-18 weeks kill 29-73% (respectively) of adult snails.	Darby et al. 2008
Hatchling and small juvenile snails less tolerant of drydowns than pre-reproductive adults (≥70% of 6-15-mm snails survived >4 wks, while 0-50% of snails 3-5-mm survived after 4 wks).	Darby et al. 2008

[a] = Most common based on available studies, but other species with similar structure also support oviposition.

[b] = During studies, pickerelweed was the most common, but this does not necessarily reflect optimal conditions.

associated with these trends and associations are presented in Chapter 10, Recommendations. We in no way suggest these are definitive targets that, once achieved, will result in full recovery of the kite population. Again, we emphasize that the key to adaptive management is working from the current foundation of knowledge (which clearly has significant gaps, see Chapters 10 and 11 and reviewers' comments in Appendix B), setting targets, implementing management activities, and then monitoring the response. Success reinforces the validity of the targets, while failure requires that we reevaluate the targets and make adjustments. For example, low nest success associated with foraging patches with recommended minimum snail densities of $0.2/m^2$ would suggest that target snail densities may need to be higher than thought necessary to support kite foraging and nesting.

Significant information gaps exist with snails, but we can associate relatively high snail densities and egg cluster production with a range of plant community types, plant densities, and hydrologic conditions (Table 9-2 [on previous pages]). These trends and associations (Tables 9-1 and 9-2) form the foundation for management targets and research/monitoring needs presented in Chapters 10 and 11. As far as restoration and management of habitats for snail kites and apple snails, hydrology has an over-riding influence on both species. Snail kite reliance on apple snails requires that restoration and management activities promote sufficient apple snail recruitment and associated snail densities, **even if on occasion** those hydrologic conditions temporarily do not support kites. For example, apple snail reproduction benefits from breeding season water depths on the low end of those documented for kites (compare Tables 9-1 and 9-2). In order to support recovery of a low-density snail population in a critical wetland, it may be necessary to temporarily maintain water depths below those that support kites. This may result in a dry down, which, depending on the duration, may have little impact on apple snails, but will cause any kites in the local area to emigrate. At least historically (based on data collected in the 1980s and 1990s, see Chapter 5), the snail kites' nomadic tendencies permitted temporary refuge in other wetland units until recovery of snails in critical wetlands could be achieved. Today, their options may be more limited due to low apple snail densities in wetlands that kites had frequently occupied. Clearly, the most direct and immediate hydrologic influence on both snail kites and apple snails is when the water table falls below ground level; these dry downs eliminate opportunities for kites to forage and nest (Chapter 5), and for apple snails to move, mate, and lay eggs (Chapter 6). More work is needed to evaluate a range of dry down conditions (duration, timing, return interval, etc.) that influence apple snails and kites. It also appears that there are upper limits to depths that benefit apple snails (Table 9-2), and likely, kites (Chapter 5). However, defining the upper boundary of what constitutes suitable water depths for these species, and why, requires

further study. Research recommendations on this and other pertinent topics are presented in Chapter 11.

The immediate responses of apple snails and snail kites to current hydrologic conditions do not capture the complexities of the relationship between hydrology and suitable habitat conditions that support these species in the long term. Kites and snails respond to changes in hydrology and habitat at different temporal and spatial scales. For example, microtopography may be critical to a portion of a local snail population (i.e., small areas of refugia during generally dry conditions), but this would not be so for kites that require much larger areas of flooded marsh. Similarly, apple snails can emerge from dry down conditions within days of reflooding and resume egg-laying (at least to some degree), whereas kites may not return to a dry down-impacted area for years (Bennetts et al. 1998a). Bennetts et al. (1998a) discussed the need to consider the potential impacts of water depth on snail kites at three temporal scales:

1) Current water depth and concurrent effects on snails and kites (e.g., kites abandon an area if depth drops below 10 cm; Kitchens et al. 2002);

2) Recent past hydrologic conditions that impact prey availability for kites (e.g., hydrologic conditions in year-1 affect snail recruitment, and therefore snail availability, in year-2; Darby et al. 2005, 2008, and 2009); and

3) Longer-term hydrologic regimes that influence habitat suitability (e.g., prolonged inundation can convert wet prairie to lily-pad-dominated slough communities [Zweig and Kitchens 2008], which support fewer snails [Karunaratne et al. 2006]).

The amount of available data that addresses hydrology at these three temporal scales varies for snail kites and apple snails. The response to current water depth, especially low water conditions, has received the most attention for both species. For snail kites, recent past hydrologic conditions have been considered primarily in terms of the recovery from a drying event, with an approximately 1-3-year lag phase required for the wetland to return to a condition that can support kites. Presumably this lag phase reflected an impacted snail population that needed time to recover. However, depending on the timing and duration of drying events, there may be little impact on snails (Chapter 6), so the mechanism behind the lag phase for kites to return has yet to be determined. Recent past hydrologic conditions are critical to apple snail population trends, since the prior-year egg cluster production has a strong influence on current-year population status. In other words, the current

available prey base for kites reflects the prior-year hydrologic conditions that greatly influence apple snail egg cluster production (Chapter 6).

In terms of a long-term hydrologic regime influence, the long-term monitoring data available on snail kites have provided some opportunity for analyses. As described in Chapter 5, however, there has been some disagreement among investigators regarding a suitable hydrologic regime that supports kites. Bennetts et al. (1988) concluded that kites tend to nest in areas where dry downs occur at least every four years, and as often as every 1.9 years, in portions of WCA3A. Using a computer simulation, Beissinger (1995) concluded that kite populations increased when drought intervals were greater than 3.3 years, with even higher population growth rates when the return interval increased to over 4 years. Bennetts et al. (1998a) in turn argued that such prolonged inundation results in habitat degradation with negative impacts on snail kites. Martin et al. (2008), also using a computer simulation, concluded that the relatively wet period of 1992-1999 resulted in habitat degradation with eventual negative impacts on kites. However, increasing the frequency of a moderate "drought" from 1 in 7 years to 4 in 7 years in their simulation resulted in population growth (λ) decreasing from 1.13 to 0.92. The lower (λ) was influenced mostly by a decrease in adult fertility.

Different conclusions from different studies may be resolved as snail kite demographic analyses incorporate spatially explicit water depths (as opposed to stages, see Appendix C), more details on the spatial extent and duration of drying events, changes in plant communities, and apple snail abundance. Martin et al. (2008) contrasted their contradictory conclusions regarding the impacts of moderate drying to those presented in Bennetts (1998, dissertation). However, they did not address fundamental differences in hydrologic conditions during the Bennetts' period of study compared to that in Martin et al. (2008). It should also be noted that the direct hydrologic associations concluded by Martin et al. (2008) did not consider the fact that snail densities were found to be quite low in major wetland units (e.g., LOKEE, WCA2B, WCA3B, and WCA3A) in 2004-2007 (see Chapter 6). Once snail densities reach these critically low levels ("critically low" being a level that still needs addressing), kites may be responding to a lack of food, even though habitat conditions (e.g., plant communities) and water depths are suitable for foraging. How these disconnected data sets (e.g., snail kite and hydrology relationships and independent studies of snail density and kite foraging) should be interpreted remains a critical question that drew disagreement from some reviewers of this document (see Appendix B). Whereas several reviewers agreed that snail availability as measured by snail density (or snail standing stock, as suggested by one reviewer) provides valuable information for interpreting kite responses to wetland conditions (see Appendix B comments by C. Ruehl [e.g., peer

review form #7, Comment #31] and R. Bennetts [Comment #10, #17], for example), another questioned the value of such information (see Appendix B comments by Z. Welch [e.g., #44, #51, #52]).

The long-term hydrologic regime may have direct effects on snails (e.g., increasing dry down frequency may decrease snail recruitment), and more indirect effects through their habitat structure. For example, prolonged flooding of an area for several years may result in loss of sawgrass for oviposition, which may in turn negatively influence egg cluster production. In addition, given lack of recovery of native snail populations in wetlands like WCA3A (see Chapter 6), managers may be faced with targeting hydrologic conditions to support apple snail recovery, but these conditions may not be conducive to kite foraging and/or nesting. For example, conditions such as those observed in 2002 in WCA3A (considered moderate drought by Martin et al. 2008) were found to be the most productive conditions for apple snails from 2002-2005 (Darby et al. 2005, 2009). However, with critically low snail densities, this may be a temporary trade-off for the long-term recovery of the snail kite. Martin et al. (2008) concluded that these moderate drought conditions (as in 2002) should be avoided in support of kites. Again, this type of trade-off and how these contradictory conclusions (see Chapter 5) should be resolved requires more attention (see reviewer comments in Appendix B).

There may never be enough empirical data to fully understand the wide range of seasonal water depths, recession rates, dry down scenarios, etc., which probably influence snail kites over their entire network of habitats over time. Computer simulations developed for snail kites and linked to those developed for apple snails may prove to be a valuable tool (Chapter 8). However, snail kite simulations thus far have not included snail densities, and the apple snail model is still in development. The incorporation of spatially explicit depth data is now possible through EDEN (although it is limited to wetlands south of LOKEE). EDEN now includes hind-casting so that kite and snail data collected in the past ~20 years can be analyzed with water depth estimates. In addition to the more complex demographic computer simulations, spatially explicit, depth-based tools to identify suitable conditions for snail kite nesting and apple snail oviposition in critical wetlands like WCA3A are also in development (Chapter 8).

Although descriptions of snail kite ecology date back several decades, most of the quantitative assessments of habitat and hydrologic influences on kite demography have a less than 20-year history. Similarly for apple snails, some important field data and life history descriptions date back several decades, but the vast majority of available data have less than a 15-year history. Consequently, much of what we understand about kite and snail abundance and distribution among wetland units reflects

conditions documented in the past 20 years or less. It may be, for example, that *Rynchospora*-dominated prairie habitat, or the historic ridge and slough habitat, had tremendous value for apple snails and snail kites, but both of these habitats have been lost or degraded in critical kite use areas in the past 20 years (Zweig and Kitchens 2008, Lodge 2010). Similarly, although the vast majority of snail kite recruitment in the late 1980s through 1990s occurred in WCA3A, we should not assume that restoring WCA3A to conditions that once again support hundreds of kite nests is sufficient for long-term recovery of the snail kite. Perhaps other areas less frequently used (e.g., ENP), even if used only periodically, are critical to reversing the negative population trend for snail kites.

The degree to which kite mobility and movement frequencies may influence kite demography, and their response to changes in hydrology and habitat condition, has also been debated. Martin et al. (2007c) concluded that natal philopatry in snail kites has a greater influence on wetland occupancy than previously concluded (Bennetts and Kitchens 1997a). This in part may reflect that the analyses in Martin et al. (2007c) focused on annual wetland occupancy within and between regions (i.e., several wetland units grouped to define a region, see Chapter 5), whereas Bennetts and Kitchens (1997a) reported natal wetland occupancy on a per wetland basis. There is also a discrepancy in how natal philopatry is defined (see R. Bennetts Comment Matrix, Comment #7 and #8, Appendix B). Regardless of these perspectives, it is clear that considerable variation in hydrology, habitat condition, and apple snail availability occurs between wetland units within a region as well as between regions at any given time, and conditions within a wetland vary from year to year (Bennetts and Kitchens 1997a, Darby et al. 2005, Karunaratne et al. 2006, Darby et al. 2006). Since many wetland units throughout the kite's range are managed independently, reports of movement and occupancy at the level of individual units provides pertinent information to managers. Limited data may preclude statistical analyses at this level, but reporting such data gives management the opportunity to track patterns of kite use in their wetlands. The distribution of snail kites shifts year to year, and wetland units with relatively little kite use can attract kites later when a sufficient food supply and suitable nesting conditions exist (e.g., LOKEE in 2012, see Chapter 5). Despite some disagreement regarding the relative importance of peripheral habitat use (see review comments, Appendix B) and the influence of natal philopatry (as just described) on snail kite distribution among wetland units, it is clear that snail kites still depend on a network of wetland units from Orlando southward to ENP. Water and habitat management still must factor in the dynamic nature of this vast landscape of wetland units, and include careful consideration of the large spatial and long-term temporal scales at which snail kites operate (Bennetts and Kitchens 1997b, Bennetts et al. 1998a).

A multi-species approach has been emphasized in the South Florida Multi-Species Recovery Plan (USFWS 1999) and CERP, and continues to influence decisions on water management and how components of the plan are implemented (USFWS 2010). At times, concerns have been expressed that different species have contradictory hydrologic needs, but for avian species at least, a panel of experts concluded that these concerns were exaggerated (SEI 2007). This panel further concluded that the needs of these avian species, including snail kites, would be met through CERP. The avifauna of peninsular Florida wetlands evolved in a large and complex system that varies in terms of habitat quality, at times favoring some species over others. They co-exist in the system but do not necessarily occupy the same portion of the system simultaneously; many species, including the snail kite, readily shift their distribution to target the most suitable habitat conditions at any given time (SEI 2007, also see comment #20 by R. Bennetts, Appendix B). In this document, we summarized the available information on hydrologic and habitat conditions that influence snail kites and their prey, and we made recommendations based on that information (Chapter 10). Our mission in developing this document was purposefully limited to describing how best to support apple snails and snail kites, clearly not a multi-species approach. The difficult decision of weighing management options in support of kites and snails as opposed to other management priorities lies with the stakeholders responsible for these species and the wetland units they occupy. Fortunately, both apple snails and snail kites are adapted to spatial and temporal fluctuations in the wetlands they depend on, so that the range of potential habitat and water management options may be sufficiently varied to accommodate the needs of these and other species.

CHAPTER 10: RECOMMENDATIONS FOR MONITORING, RESTORATION, AND MANAGEMENT IN AN ADAPTIVE MANAGEMENT CONTEXT

This chapter presents recommendations for snail kite and apple snail monitoring, management, and restoration in an adaptive management context. Recommendations draw on the many existing publications as well as monitoring, research, and special reports (e.g., USFWS 1999, SEI 2007) on kites and snails. Recommendations came directly from past or current publications or reports, from our review of existing literature, from DOI cooperators, or from external reviewers of this document (i.e., species and habitat experts, the management community). Recommendations were based on information available to us at this point in time; the next chapter of the report addresses gaps in our knowledge and lists recommendations for research to assist in filling information gaps. Many recommendations presented in this chapter will undoubtedly be familiar to the reader. Some have been made by various researchers or managers in the past, but because of their importance, they are repeated again here. Most recommendations apply system-wide, throughout the snail kite's range in Florida, but site-specific recommendations are made as appropriate.

Adaptive management is based on a simple premise: management policies and subsequent activities are experiments from which we should learn (Lee 1993). We often must make decisions, create policies, and take action with incomplete information about the resource that we are trying to support. We will not address the complexities of decision theory here, but simply make clear that in changing hydrologic and habitat conditions to support kites, we must learn from the management results and continuously reevaluate what we think we know about snail kites and apple snails.

At its core, adaptive management is a mindset. We must embrace the fact that despite 40 years of monitoring snail kites, we have more to learn. To learn, we must accept new knowledge (even if it contradicts what we thought we knew) and be willing to consider alternatives to the reigning paradigm for the resource of interest (Meffe et al. 2002). Information that supports good management decisions should be a priority. This means reporting research and monitoring data in a way directly usable by natural resource agencies in a timely fashion. Monitoring programs should be designed with input from the management community.

Learning cannot occur if we do not have performance measures (Meffe et al. 2002). Performance measures refer to outcomes (e.g., particular water depths, snail kite nest success in specific areas or statewide, certain snail densities) that can be measured and associated with a particular management action. Performance measures require monitoring of the system. In the

case of snail kites, there are two resources currently monitored on a routine basis: snail kite demography (population size, nest success, number of young produced per year) and water stages (and in some cases, spatially explicit water depths). Snail density data are not being collected at a scale relevant to kites, and in some years no data are being collected at all. Landscape-level plant community monitoring (i.e., the acreage of foraging habitat available on a wetland-unit basis) also has not been accomplished throughout the kite's network. An overarching recommendation for management related to snail kite recovery is to revisit performance measures in light of new data collected in the last 5-10 years, and to modify and/or create new ones with as much specificity as possible (e.g., the number of days during the breeding season at certain critical depths) (see Section B).

One of the strongest suggestions made by members of the management community in reviewing a draft of this document was to include specific recommendations for hydrologic management of wetlands used by snail kites (see review comment matrices from reviewers from the St. Johns River Water Management District [WMD] and South Florida WMD; Appendix B). They called for specific quantitative targets for hydrologic conditions, such as seasonal water levels, return frequencies of drying events, and water level recession and ascension rates. We agree that this information is critical. When we began work on this project, we anticipated there would be more such information available. Although there is some information available now, the information base is far from complete; we also recognize that some information specific to management entities may exist, but are currently not readily available. Studies often were conducted in only one wetland location or in some otherwise limited context. The scope of this document was limited to existing publications and reports; we were not able to conduct new analyses or meta-analyses based on existing or new data. Given this context, it was not possible to develop many specific, on-the-ground management recommendations that applied across the range of the snail kite. This is a task that needs additional, focused attention. While we have not put forth many specific recommendations of quantitative hydrologic targets, we have developed a number of recommendations, including one to create a Snail Kite Coordinating Team, which should focus on quantitative targets as a high priority. The recommendations in this chapter were placed in the following categories: General Recommendations, Recommendations for Management, Recommendations for Monitoring, and Recommendations for Coordinated Information Gathering, Analysis, and Reporting.

Based on the external review of the document, we have added and deleted a few recommendations from previous drafts, and we have combined some recommendations to minimize redundancy. Because these changes will make it difficult for the reader to follow the

reviewer comments (in Appendix B) for a given recommendation, we created a table showing the recommendation number in this version compared to those in the drafts commented on by reviewers (see Appendix B).

A. GENERAL RECOMMENDATIONS

We found several recommendations made in special reports on the snail kite to be quite general. They are presented here to provide an overarching context for recommendations for snail kite and apple snail conservation and management. On-the-ground natural resource managers require detailed targets for hydrology and vegetation, for example, and subsequent sections of this chapter have more detailed recommendations addressing such management targets.

A-1. Recommendation: Conserve and effectively manage (and restore, in some cases) the network of habitats, including peripheral habitats (as possible), used by the snail kite in central and southern Florida.

> *Background*— "Spatial and temporal variation is an integral part of the Florida wetlands landscape, and kites are well adapted to this variability....It is the mosaic of hydrologic regimes and local conditions that enable kites to have habitat available during a variety of hydrologic conditions (both low and high water conditions)" (Bennetts and Kitchens 1997a). For their long-term survival, kites need "to have an extensive network of habitats, including peripheral habitats, that enables kites to have some areas available when inevitable and periodic fluctuations in the quality of other habitats occur" (Bennetts and Kitchens 1997a). For this reason, "... habitat management for the kite should focus on the entire network of central and south Florida wetlands, rather than individual wetland units" (Martin et al. 2002b). Furthermore, many researchers have recommended maintaining a mix of the plant communities used by both snail kites and apple snails (e.g., Sykes 1983b, Turner 1996, Bennetts and Kitchens 1997a). Examples of areas that need significant restoration, especially of Florida apple snail populations, include LOKEE and WCA3A (Darby 2006, Darby et al. 2009).

A-2. Recommendation: Management and conservation for snail kites should focus on longer-term trends in snail kite numbers, reproductive success, and habitat quality, as well as shorter-term trends in apple snail populations (prey availability).

Background— Martin et al. (2002b) recommended that management should focus on long-term trends in kite numbers and habitat quality, rather than short-term fluctuations that are a part of the snail kite's natural life history (also see Bennetts and Kitchens 1997b). We would add that trends in apple snail abundance, the kite's nearly exclusive prey, would also indicate wetlands where more active management for kites may be needed. Restoring an area with low snail densities (e.g. WCA3A) may require several years of hydrologic conditions that support snail recruitment.

A-3. Recommendation: As advocated in recent years by multiple researchers, snail kite and apple snail habitat should be allowed to experience occasional dry downs similar to those occurring under natural conditions. Research, *including the analysis of existing data*, needs to be conducted regarding the timing, intensity, duration, and frequency of dry downs to benefit apple snails and snail kites.

Background— Both snail kites and apple snails are adapted to seasonal fluctuations in water depths. Both are also adapted to periodic dry down conditions— kites by moving to other wetland units (see Chapter 5), and snails by aestivating (see Chapter 3 or 6; assuming the duration of dry down does not exceed their aestivation capacity). As mentioned throughout this report, these conditions are necessary to maintain snail kite and apple snail habitat in the long term.

B. RECOMMENDATIONS FOR MANAGEMENT

B-1. Recommendation: Develop hydrologic targets for management in wetlands deemed critical to snail kites using a similar approach as that used in the USFWS Multi-Species Transition Strategy for WCA3A (USFWS 2010). Targets are needed for seasonal water depths, recession and ascension rates, and dry down return intervals and durations. Also see Recommendation 11-1 in Chapter 11. Note that we are not necessarily endorsing the specific hydrologic recommendations stated in the Strategy for WCA3A, but rather the overall approach taken.

Background— The USFWS Multi-Species Transition Strategy for WCA3A (the Strategy) was developed with the intent of restoring hydrology in the WCA to support snail kite nesting and foraging, while also considering the needs of other species and habitats (i.e., wood storks, wet prairies, and tree islands; USFWS 2010). The Strategy was developed by a team of species experts, hydrologists, and biologists familiar with WCA3A. The intent of the Strategy was to promote decision-making with multiple

interests and to assist in evaluating potential water management actions in the WCA. The Strategy uses current information on the various species and plant communities to recommend water levels/depths during three time periods (i.e., height of the wet season, kite pre-breeding season [January], and latter part of the peak kite breeding season when water levels are at their lowest [May 1-30]) and recession and ascension rates. [The NPS (A. Lo Galbo, NPS, pers. comm.) has expressed concern regarding specific recommendations in the Strategy for WCA3A, including that it may negatively impact ridge and slough habitat]. Again, we are not necessarily endorsing the specific hydrologic recommendations stated in the Strategy, but rather the overall approach taken.

B-2. Recommendation: In WCA3A, strive for water levels at the start of the dry season that more closely mimic the natural system, so that water levels would be likely to persist during the kite breeding season under typical drying rates. This recommendation is a more general version of that recommended by SEI (2007) to address unsuitable conditions that had been occurring during kite nesting in WCA3A (see below).

Background— USFWS (2010, page 9) described the unsuitable hydrologic scenario in WCA3A as follows: "High water conditions during the pre-breeding season can act as an ecological trap in which kites build nests at higher ground surface elevations and are then left "high and dry" when water levels recede (Sykes et al. 1995, Cattau et al. 2008)." Such conditions may lead to "enormous difficulties" foraging and a decrease in nest success and juvenile survival (Cattau et al. 2008 and 2009). Water depths that are too high for apple snails (i.e., during the snail breeding season) **on a sustained basis** may lead to less egg production and lower apple snail populations in subsequent years (as described in Chapter 6). Also, inundation on a sustained basis has degraded snail kite/apple snail habitats (e.g., Bennetts et al. 1998a, Zweig and Kitchens 2008).

B-3. Recommendation: Managers of lakes and wetlands used by snail kites should explore and advocate methods or timing of exotic plant control (and other management activities) that are least likely to result in harm to snail kite nests or apple snails.

Background— Activities such as the spraying of invasive plants can lead to the death and subsequent collapse of vegetation, which would be a concern if the vegetation contained a snail kite nest. Spraying may also be of concern for apple snails, if vegetation used by snails for oviposition or climbing is lost. Rodgers et al. (2001) described the use of buffer zones around nests to avoid the negative impacts of spraying on kite nesting on

central/south Florida lakes. Cattau et al. (2007, 2008, and 2009) further recommended that water, vegetation, and other management activities in the Kissimmee Chain-of-Lakes (which has been used increasingly by nesting kites in recent years) be planned and carried out to avoid or minimize adverse impacts to kites.

B-4. Recommendation: For wetland units deemed critical to snail kites, if adult-sized apple snail densities are reported to be less than approximately 0.1-0.2 / m^2, consider management options (see Recommendation B-5) to increase native apple snail densities and otherwise improve snail availability to kites (e.g., via plant management activities). This minimum snail density threshold may need to be revised as additional data are collected.

Background— Cumulative evidence from several studies indicates that snail densities less than approximately 0.1-0.2 / m^2 result in: 1) fewer foraging kites, 2) significantly longer times for kites to capture snails, and 3) a decrease in foraging bout success (see details in Chapter 7). Conversely, large numbers of nests in WCA3A have been associated with snail densities > 0.4 snails/m^2 (Bennetts et al. 1988). Greater snail availability (as indicated by snail density) may be needed in support of nesting kites provisioning for their young; Cattau, Fletcher, and Darby (*manuscript in preparation*) observed an increase in number of young fledged per successful nest as snail densities in the vicinity of these nests increased from 0.25 to 1.0 snails / m^2.

B-5. Recommendation: In situations where snail availability is deemed too low to support snail kite foraging and/or nesting (see Recommendation B-4), create, to the degree possible, a hydrologic "window of opportunity" that supports apple snail recruitment, growth, and survival (see Chapter 6). Based on available information to date, this would mean that between February and June in a particular wetland, an effort should be made to maximize the number of days over the largest area possible, wherein depths stay above 10 cm but do not exceed approximately 40-60 cm. Note that the **upper limit of this depth range, in particular, may need revision** following additional field and mesocosm studies.

Background— To ensure the persistence and/or recovery of apple snail populations in a given wetland, the peak period of snail mating, egg-laying, and juvenile snail growth should be the focus of management activities. Darby et al. (2005) found that despite abundant adult snails, total annual egg cluster production declined by an order of magnitude when depths exceeded ~40-50 cm in the peak snail breeding season. Darby et

al. (2009) also found that within a wetland unit, per capita egg cluster production was greatest in depths between 10 and approximately 40 cm.

B-6. Recommendation: Engage in habitat management practices that promote plant community composition to support apple snail reproduction and relatively high snail densities. Management may include practices such as hydrologic manipulation, prescribed fire, and possibly more intensive plant management practices.

Background— See details in Chapter 6. In general, emergent plants with >6 mm diameter stems or leaves support oviposition (Turner 1996). In the Everglades, egg cluster production is concentrated in the sawgrass ecotone (Darby et al. 1999), and highest snail densities have been associated with low to moderate stem density (or leaf density) wet prairie (dominated by Gulf Coast spikerush [*Eleocharis cellulosa*], maidencane [*Panicum hemitomon*], or Egyptian paspalidium [*Paspalidium geminatum*]) bordering sawgrass. Management activities that promote habitat heterogeneity, especially where ecotones are formed by sawgrass and juxtaposed prairie, are recommended. Darby and Karunaratne (unpublished observations) found no eggs on white water-lily (*Nymphaea odorata*); in addition, white water-lily-dominated sloughs supported fewer snails than marshes dominated with emergent species (Karunaratne et al. 2006). It may be that other types of communities, e.g., beakrush (*Rynchospora*) prairie, were important to snails, but these communities have diminished due to changes in hydrology (Zweig and Kitchens 2008).

In lake habitats (e.g., LKISS, LTOHO), egg cluster production was concentrated on bulrush (*Scirpus* sp. [now *Schoenoplectus* sp.]) and pickerelweed (*Pontederia cordata*; Darby 2006). On lakes, greatest juvenile snail densities were found in the SAV tape grass (*Vallisneria americana*). Other plants, such as lance-leafed arrowhead (*Sagittaria lancifolia*), also support egg clusters, but are generally less wide-spread than pickerelweed in central Florida lakes. Darby (2006) found no apple snails in high density, monoculture pickerelweed and floating mats. While conducting the work described in Kitchens et al. (2008), however, some snails were captured in crayfish traps in this type of vegetation on LTOHO (Z. Welch, pers. comm., Appendix B comment matrix). Unconsolidated organic substrates associated with yellow cow-lily (*Nuphar luteum*) also did not support apple snails, but after a drawdown this plant community type supported growth of SAV and, eventually, snail densities that supported kite foraging (Darby 2007).

Relative habitat preference for apple snails is based on data currently available, and it is possible that nutrient inputs and changes in hydrology have resulted in less than "ideal" conditions to support apple snails (i.e., the plants available to snails today may be different than they were historically).

B-7. Recommendation: When managed drawdowns are conducted on lakes in central Florida, they should be timed, as much as possible, to avoid the peak period of apple snail reproduction (March or April to June) **and/or** be of a short enough duration (<12 weeks) to allow for the survival of most snails that become stranded in dry marsh.

Background— Darby et al. (2008) found that if water levels and temperatures are conducive after the typical peak oviposition period, reproductively mature snails would mate and lay eggs after a dry down event (although to a lesser extent). Such consideration of the timing and duration of a managed drawdown/dry down would minimize reductions in the apple snail population.

B-8. Recommendation: Implement public education (and possibly boat checkpoints) and policies, similar to those used to prevent the spread of hydrilla, to reduce the spread and potential impact of exotic ampullariids, especially *Pomacea insularum*, in Florida.

Background— Based on observing exotic snail egg clusters on boat hulls and finding small (< 5 mm-diameter) snails clinging to boat hulls and field gear, P. Darby (UWF) believes that efforts to contain the spread of the exotic at Florida lakes should be made. Public education and boat checkpoints have been used in other states for invasive exotic aquatic organisms. For example, the State of California posts informative posters educating the public on visual identification of exotics and how to properly clean fishing gear and boats. Many states (e.g., California, Wyoming, and Michigan) have long-established boat launch checkpoints where officials visually inspect the hull and transom of a boat before it is launched.

C. RECOMMENDATIONS FOR MONITORING

C-1. Recommendation: Provide an annual wetland condition assessment report for wetland units deemed critical or important to snail kites in the last 30 years (e.g., WCA3A, LTOHO, BCMCA/BCWMA, LOKEE; see "Critical Habitat and Other Important Wetlands Used" in Chapter 3). The assessment should eventually be linked to a habitat suitability index (see Recommendation 11-2 in Chapter 11) and include information on hydrology, prey availability,

and plant communities. The wetland condition assessment should include spatially explicit water depths for the current year (kites respond directly to current conditions), the previous year (as prior year depths affect snail egg production and current-year snail density), and previous 5-10 years, the latter to identify long periods of inundation or frequent drying events that may result in habitat degradation and/or low snail densities. The reported depth conditions should include some degree of ground truthing, until depth estimation tools (e.g., EDEN) have proven to be sufficient for the assessment.

Background— The idea that snail kites are influenced by hydrologic conditions at three temporal scales (current, prior year, long-term) was presented in Bennetts et al. (1998a). The number of days at certain depths, especially during the breeding season, influences snail kite nesting and apple snail reproduction. The Snail Kite Nesting Depth Preference Tool (Lo Galbo et al. 2010) provides the type of information that would be included in the report. Similarly, the number of days at suitable depths for apple snail egg-laying has been used to evaluate prior year conditions for recruitment (see Chapter 9, Darby and Wight 2011). Other depth criteria could also be considered (e.g., rates of depth rise or fall, number of days in dry down condition). Darby and Wight (2011) found EDEN data to closely match field depth measurements. Although EDEN does not apply to all wetlands in the kite's range, other sources of information (including field measurements, topographic information, and stage data), can be used to show hydrologic profiles for wetland units (see Darby et al. 2002, Darby et al. 2004, Darby et al. 2008). This wetland condition assessment should ultimately include an estimate of the area of suitable kite foraging habitat and any changes in nesting substrate availability, hopefully through the development of remote sensing techniques currently being considered by the USACE (e.g., unmanned aerial vehicles; F. Percival, FL Cooperative Fish and Wildlife Research Unit, pers. comm.).

This annual wetland condition assessment is linked to the tasks identified in Recommendation D-1 of the Snail Kite Coordinating Team.

C-2. Recommendation: Regarding long-term monitoring for snail kites, the snail kite range-wide survey should be extended south of Shark River Slough in ENP (recommendation suggested by NPS and USFWS during development of this document). This would include monitoring in Taylor Slough and the C-111 detention basins. An important component of this long-term kite monitoring is the long-term monitoring of apple snail populations (see Recommendation C-3).

This additional monitoring may be especially relevant with the construction and operation of the C-111 detention basins.

Background— ENP staff recently noted increased sightings of snail kites in the C-111 detention basins (A. Lo Galbo, pers. comm.). Monitoring for snail kites in Taylor Slough and the C-111 detention basins was not included as part of the C-111 Spreader Canal Project.

C-3. Recommendation: Implement an apple snail monitoring program across the range of the snail kite. Such a range-wide effort should take advantage of monitoring that is ongoing and being conducted at the project-level scale (e.g., in WCA3A as funded by USACE). Sampling protocols should be standardized, cost-effective, and directly supportive of management. Priority areas to be monitored could be recommended by the Snail Kite Coordinating Team.

Background— USFWS (2007) recommended that snails be monitored in all of the areas that snail kite surveys are conducted. They further recommended the monitoring program should be conducted annually for at least 10 years in order to encompass long-term climate cycles. NPS and USFWS recently reiterated this recommendation (A. Lo Galbo, pers. comm.), and pointed out the need to include monitoring on the Kissimmee Chain-of-Lakes. A. Lo Galbo also recommended that apple snail monitoring should be considered at a regional program level (e.g., RECOVER – MAP), as well as on a local project-level scale (e.g., Tamiami Trail 1-mile bridge, C-111 Spreader Canal, etc.). Knowledge of the forage base of the kite will assist in explaining trends in snail kite nesting, nesting success, and survival, and will inform managers as to whether an adequate forage base exists for snail kites on the wetlands monitored. Snail density estimates are an essential component of conceptual and quantitative models if the objective is to better understand kite demography, movements, and habitat use (see Chapter 7). Linking data on snail availability to kite demography would also better enable quantitative connections between the influences each of the species has on the other (i.e., predator-prey relationships).

Sampling could include a combination of 1) $1m^2$ throw traps to estimate snail density; and 2) egg cluster counts to evaluate recruitment potential for a given population and whether current hydrologic conditions are suitable for snail egg-laying. Additional tools could also be explored (e.g., capture times for kites foraging on snails, see Darby et al. 2012). Snail densities would be categorized as adequate (or not) based on information to date regarding snail kite foraging needs (see Chapters 5 and 7). At this time, we are

only aware of large-scale snail sampling being conducted in LOKEE (by LG2 Environmental Solutions, Inc. via USACE contract) and in WCA3A (by P. Darby via USACE contract ending 2013).

Such an effort could be accomplished through a Monitoring Network, possibly involving several different working groups (e.g., contractors, universities, federal and state agencies), but that has a standardized sampling protocol and integrated data management system. Participation from citizens in collecting data on snail egg clusters may also be considered. A Network would benefit snail kite conservation and recovery by keeping snail kite and apple snail managers and researchers informed of patterns/trends in snail density and reproduction over a larger scale than might otherwise be accomplished with one working group. One leading expert could train the individuals working in the network to ensure consistency (in protocols) in sampling and data recording. Data could be made available in a centralized location, and a single annual report of available data could be produced.

C-4. Recommendation: Monitor the spread of exotic apple snails and their influence on native flora and fauna, and if necessary, develop techniques to reduce or eliminate the spread of *Pomacea insularum* (e.g., SEI 2007). Also see research recommendations that directly address questions about this exotic species.

Background— The exotic apple snail *P. insularum* may prove problematic in wetland habitats in Florida, but a direct link to habitat destruction and competition with native snails has not yet been made. Snail kites dropping large exotic snails have been observed in the past, but the overall negative impacts on the snail kite population remain unclear. In some wetlands *P. insularum* provides the primary food source for kites, because native snail populations had already declined (e.g., on LTOHO). However, monitoring is recommended in order to provide data that may identify negative impacts of the exotic snail on Florida aquatic ecosystems, including snail kites and native apple snails.

C-5. Recommendation: Implement a monitoring program of snail kite foraging success/efficiency, nest success, and recruitment of offspring as related to apple snail densities and foraging habitat characteristics (i.e., hydrologic conditions, vegetative community compositions; from Cattau et al. 2008 and 2009). An effort to integrate investigations of the effects of hydrology on snail kites, apple snails, and their habitats was also called for in the SEI (2007) report. Also see Recommendation D-4 for such efforts using existing data.

Background— Cattau et al. recommended the program specifically for WCA3A, pointing out that 3A has historically been important. We believe, however, that other wetland units/lakes important to snail kites should be included as well. Cattau et al.'s (2008, 2009) stated reason for this recommendation was to assist natural resource managers that presently lack an integrated approach to managing hydrology and vegetative communities for apple snails and snail kites. Although some useful information is available, such as publications on habitat structure and snail densities (Karunaratne et al. 2006), snail densities and presence of foraging kites (Darby et al. 2006), and the role of vegetation structure and snail abundance in the selection of foraging habitat by kites (Bennetts et al. 2006), this information does not apply specifically to nesting snail kites. The information obtained from such a snail kite foraging/nesting monitoring program would also be critical to snail kite modeling efforts. Scale issues need to be addressed when linking snail sampling data to kite demography data (see Recommendation D-5 in this chapter).

C-6. Recommendation: Given that the estimated snail kite population has decreased considerably in recent years, and snail kites disperse during drought conditions or poor foraging conditions, the use of a clearinghouse for snail kite sightings should be considered. A network of professional biologists and bird watchers throughout the kite's range could be used to report sightings of kites. Online approaches, such as eBird, should also be considered.

Background— The use of a clearinghouse was described by Takekawa and Beissinger (1989). As kites disperse during dry down conditions or for other reasons (e.g., low snail densities / poor snail recruitment), it may be difficult to determine where kites move outside of the survey area. Having an established network of state, federal, and other professional ecologists throughout the state that can report/share this critical information may prove extremely valuable. Z. Welch (Appendix B, comment matrix comment #49) reports that some bird watchers in Florida have been reporting kite sightings to the UF monitoring team. If that informal system is working well, perhaps efforts could be made to expand participation. In 2002, the Cornell Lab of Ornithology and National Audubon Society developed eBird to maximize the usefulness and accessibility of bird observations by recreational and professional bird watchers (eBird, http://ebird.org/). Such an online system of reporting may be useful for obtaining additional sighting information on the snail kite.

C-7. Recommendation: Collect data on nest detection probability, and determine whether effort is needed to increase detection in order to find and band more juveniles.

Background— A critical part of the snail kite population monitoring program is having a sufficient number of marked individuals in the population (to maintain precision; Cattau et al. 2009), yet the proportion of marked individuals within the population is declining (Cattau et al. 2009). Based on Martin et al. (2007a), juvenile detection probabilities (the proportion of young marked each year) are relatively low, but they have only been estimated for two years (0.16 in 2004 and 0.35 in 2005). After several years of increasing the proportion of young banded, and as these young grow into a range of adult age classes, we would expect to see an increase in the proportion of banded adults in the kite population. Z. Welch (Appendix B, comment matrix comment #50) suggested that nest detection is higher on lakes such as those in the Kissimmee Chain-of-Lakes, where a high proportion of snail kites have nested in recent years. The current nesting distribution, however, may change again in the future, shifting to more areas (e.g., WCAs) in which nest detection may be lower.

D. RECOMMENDATIONS FOR COORDINATED INFORMATION GATHERING, ANALYSIS AND REPORTING

D-1. Recommendation: Establish a Coordinating Team or Committee for the snail kite. The Team's responsibilities should include 1): forming a consensus on the best hydrologic and habitat conditions to support Florida apple snails and snail kites; 2) assessing the adequacy of apple snail and snail kite monitoring (e.g., is the coverage of apple snail monitoring sufficient); 3) evaluating the use of available funds and setting priorities for research and monitoring of kites and snails; 4) annually assessing, or overseeing the assessment of, habitat quality in the wetlands deemed ecologically critical to the snail kite (see Recommendation C-1), and setting priorities for snail and kite recovery in critical wetlands; 5) developing performance measures for the kite, snail, and their habitats; and 6) developing a communication plan to disseminate key information to natural resource agencies and the public (such a plan could include a multi-contributor periodic report summarizing, for example, kite nesting distribution, nesting success, prey availability, and habitat conditions). The Team should include, at a minimum: 1) those conducting major research projects on kites and snails; 2) other avian, aquatic invertebrate, and wetlands ecology experts; and 3) representatives of natural resource agencies having responsibilities for snail kites and their habitats. The team should be lead or co-lead by individuals not directly involved in kite or snail research/monitoring/ management.

Background— The snail kite is included in the South Florida Multi-Species Recovery Plan (MSRP), which is "designed to recover multiple species through the restoration of ecological communities over a large geographic area" (USFWS 1999). The plan addresses 68 federally-listed species that are endangered or threatened. For the snail kite, as for some of the other 67 species, the MSRP replaced the previously-existing recovery plan for the species (1986 plan for the kite). Recovery actions in the MSRP include species level actions (e.g., determine the distribution of the species in South Florida, and protect and enhance populations); habitat level recovery actions (e.g., prevent degradation of existing habitat, monitor habitat level responses to management actions); and restoration actions at the ecosystem/community level (e.g., restore existing degraded communities). We support the establishment, approach, and implementation of the MSRP. However, we also believe that, given the population decline of the snail kite and the reduction in the number of young produced, the snail kite needs more immediate, focused attention. Although we believe the snail kite warrants this additional attention, we are not recommending that the system be managed for the snail kite alone.

D-2. Recommendation: Although some efforts currently exist, increase collaboration and communication between and among researchers and agency personnel. Such efforts could be made at different scales (see background below).

Background— For example, a snail kite-apple snail symposium or meeting could be held once every one or two years to share kite and snail research/monitoring findings and discuss current management issues. The currently active wood stork working group lead by USFWS could provide an example for development of such a group or recurring meeting for snails and kites (R. Borkhataria, Appendix B, comment matrix comment #22). This symposium/meeting could be organized by the Snail Kite Coordinating Team. Another idea is to create a web-based forum for all working groups studying any aspect of apple snail or snail kite ecology, so that information and resources can be shared and redundancy in effort avoided. It could be created to allow access by permission only, include statements about protecting sensitive information, and provide data sharing agreements.

D-3. Recommendation: Provide an assessment of the current condition of federally designated critical habitats, and consider updating the critical habitat designation for the snail kite (USFWS 1999).

Background— Critical habitat was designated for the snail kite in 1977 and has not been changed since that time. For example, USFWS (1999) suggested the following wetlands are also important and should be considered for designation as critical habitat: LKISS, LTOHO, East LTOHO, a portion of the SJM north of State Road 60, BCNP, and marshes around the Corkscrew Swamp. An assessment of the current designated wetland units (in terms of hydrologic condition, habitat, and snail densities) would also be informative and provide potential justification for revising snail kite critical habitat.

D-4. Recommendation: In addition and prior to conducting new/more in-depth investigations of nesting snail kites (nest success, foraging success/efficiency, and juvenile recruitment) related to apple snail densities and foraging habitat conditions (i.e., hydrology and vegetative community composition) (see Recommendation C-5), new analyses **of existing data sets** should be conducted to explore possible relationships between apple snail densities (and biomass, see below) and numbers and success of snail kite nests.

Background— A significant amount of data have been collected by the kite monitoring teams from UF/Cooperative Fish and Wildlife Research Unit (W. Kitchens PI). Effort should be made to overlap and examine these data along with snail density and related data collected by P. Darby (UWF). Other researchers (e.g., Jenn Bernatis, FFWCC; Ken Meyer, ARCI; Joel Trexler, Florida International University [FIU]) also have field data that may prove valuable in this assessment of existing data. Some preliminary efforts to do this have been taken by P. Darby (UWF) and C. Cattau (UF). Estimates of apple snail biomass based on length-weight relationships (e.g., Sykes 1987b), should be included in these analyses and in future studies. This information would be important, for example, when kites are foraging in two sites with similar snail densities, but one population consists of overall smaller snails; kites feeding on this snail population may struggle to meet their energetic needs compared to kites foraging on the population with larger snails.

D-5. Recommendation: Make every attempt to report apple snail population metrics at a scale relevant to other researchers' work. For example, when sampling apple snail density to assess foraging opportunities for kites, do so at a scale that has relevance for snail kites.

Background— Many previous snail sampling efforts had the objective of learning more about apple snails themselves, so sampling was conducted at a scale relevant to snails. However, to monitor snails at a level relevant to kite foraging, snail densities or other

measures should cover a larger area that is relevant to kites. Sampling snails to assess foraging opportunities at the scale of a wetland unit may require a hierarchical approach, such as using egg cluster counts for presence/absence information, using throw traps in kite foraging areas as an indication of high-density patches, and using "stopping rules" to save sampling time/effort where randomly selected sites yield very few snails (see Darby et al. 2009).

D-6. Recommendation: In future studies and analyses, characterize hydrologic conditions based on spatially explicit water depths (which accounts for topography within a wetland unit) whenever possible. Avoid subjective terms like "drought." Kites and snails respond to water depths, not stage; reporting seasonal depths has more meaning in ecological terms and can be compared to empirical data that demonstrate kite and snail response to their environment.

Background— Efforts to objectively characterize drought conditions, such as by using ± 1 or 2 standard deviations below the mean stage (drought scores; e.g., in Bennetts and Kitchens 1997a), have been used to evaluate the regional extent of "drought" conditions. However, they have significant limitations and can be misleading in terms of understanding how kites and snails respond to hydrology (see Appendix C). Knowing the impacts of dry down conditions, for example, requires that we know actual depths, and a negative drought score does not provide that information. If drought score values or other metrics of hydrology are used for analyses, actual depth data (or stages with ground levels indicated) should be provided so ecologists and managers have a hydrologic frame of reference from which to assess the meaning of a hydrologic metric. Depth data from EDEN may be especially important for analyzing snail kite response to hydrology, but data at a finer scale may be required to understand the Florida apple snail (which uses habitat over smaller scales and for which microtopography may be critical).

D-7. Recommendation: Update this document to incorporate the findings of additional years' snail kite and apple snail monitoring, research, and analyses, and activities of the Snail Kite Coordinating Team. Updates could be made by adding a chapter with updates, or by revising the document wherever needed.

Background— Updates on snail abundance and recruitment (in some areas) and the snail kite population happen on a yearly basis. Also, opportunities to analyze the increasingly available databases like EDEN may result in new perspectives on what hydrologic conditions influence snails and kites. Paradigm shifts in what we know about snail kites

and apple snails have occurred in the last 15 years (e.g., that snails are quite tolerant to dry down conditions, and kites exhibit exploratory movements under high water conditions), and it would not be surprising to see some additional paradigm shifts in the future.

CHAPTER 11: INFORMATION GAPS AND RECOMMENDATIONS FOR RESEARCH PERTINENT TO MANAGEMENT AND CONSERVATION

This chapter provides research recommendations to address gaps in information on snail kite and apple snail management and conservation. There is some inherent overlap between some of these recommendations and those in Chapter 10, and some of the recommendations here may also have fit in Chapter 10. In the previous draft of this document, we noted that the research recommendations had not been prioritized, but that they may be for the final report (after receiving input from the agency reviewers). Three of the agency reviewers commented on this statement. One reviewer (M. Cook, see Comment #2 in Cook Comment Matrix, Appendix B) agreed with the need for prioritization, but suggested that the task should be undertaken by the Snail Kite Coordinating Team (whose formation is recommended in Chapter 10 [#D-1]). He further suggested that the development of a series of conceptual models comparable to that used in Gawlik's (2002) "prey availability hypothesis" would assist in the process. A second reviewer (R. Bennetts, see Comment #31 in Bennetts Comment Matrix, Appendix B) supported the need for prioritization and stated his belief that we should do so in the final document. He suggested that while getting agreement on the prioritization might be difficult, getting agreement on a set of criteria to prioritize the recommendations would be possible. He further stated that Chapter 11 "should emphasize research that has the greatest implications to management and/or where there has been the greatest uncertainty or disagreement among scientists." A third reviewer (S. Miller, see email correspondence sent with comment matrix, Appendix B) also suggested it would be helpful to prioritize research needs, and that this might be achieved by polling researchers.

For this final version of the document, we decided to make the prioritization of the research recommendations a recommended action for the Snail Kite Coordinating Team. We believe that the process is a task that requires more effort than we can devote to it within the context of this project at this time, and that the process will benefit from a team approach. However, starting with the comments made by the second reviewer noted above, we provide here a preliminary list of criteria by which to rank the recommendations.

- Research with demonstrable applications to management, such as recommending/refining seasonal water level targets to support snail kites and/or apple snails.
- Research that focuses on an area of uncertainty or disagreement in the scientific community and for which findings would assist in management.

- Research that significantly contributes to understanding a critical aspect of snail kite or apple snail biology/ecology that may not contribute directly to management "on the ground," but that has an important conservation application.

Based on the external review of the document, both Phases 1 and 2, we added and deleted several recommendations from previous drafts, and we combined some recommendations to minimize redundancy. We have also combined the original, separate lists of snail kite and apple snail recommendations into one larger list, as all of the recommendations are intended to ultimately benefit the snail kite. Because these changes will make it difficult for the reader to follow the reviewer comments (in Appendix B) for a given recommendation, we created a table showing the recommendation number in this version compared to those in the drafts that underwent external review. This table appears in Appendix B.

RESEARCH RECOMMENDATIONS FOR SNAIL KITES AND APPLE SNAILS

11-1. Recommendation: Taking into consideration past reports (see background below), analyses should be conducted regarding appropriate return intervals for drying events in apple snail/snail kite habitats. Such analyses could be desk-top and based on existing data.

Background— Kitchens et al. (2002) agreed with previous authors (e.g., Sykes 1979, Beissinger 1988, Bennetts et al. 1988, Beissinger 1995, Sykes et al. 1995) that habitat suitable for snail kites is inundated for relatively long periods of time (e.g., 1-5 year average return interval of drying events, with considerable variability), but that "... excessive stabilization results in a slow but steady conversion of wetlands to a more homogeneous aquatic state, degrading their habitat value for snail kites over long time scales." Bennetts et al. (1998a) suggested that the upper limit for the return interval should be more like 4 years. Furthermore, according to the work of Darby et al. (2009), the time frame for "habitat degradation" may be much shorter when it comes to apple snail populations, since a poor recruitment year can result in a dramatic decline in snail density the following year (Darby et al. 2005, 2009). Snail kite and apple snail demographic models may be instrumental in these analyses.

11-2. Recommendation: Develop a habitat suitability index for snail kites that can be used as a real-time benchmark to assess habitat conditions throughout the snail kite network of habitats (recommendation suggested by M. Cook, SFWMD, Appendix B, comment matrix comment #6).

Background- A habitat suitability index has been developed for wading birds in Florida that captures the dynamic landscape conditions to which snail kites must also respond. By using a combination of radio telemetry to track birds, and data bases for water depths (EDEN data) and vegetation classes (ARCMAP), Beerens et al. (2011) modeled wading bird movements and wetland occupancy as a function of dynamic habitat covariates (see Beerens et al. 2011 for details). The development of a similar habitat suitability model for snail kites could possibly be initiated by use of existing data for snail kite wetland occupancy (annual survey), satellite transmitter data (on-going study), and snail densities, although significant gaps (especially in prey availability) exist.

11-3. Recommendation: Conduct research on the effects of a range of hydrologic metrics (e.g., seasonal depths, recession and ascension rates) that influence and are optimal for snail oviposition and recruitment. We recommend a combination of laboratory (being cognizant of scale effects), mesocosm, and field studies.

Background—One of the recommendations in Chapter 10 for apple snails was to maximize the "window of opportunity" for snail recruitment, growth, and survival in wetlands with low snail populations. It was noted in several places in this report that the depth range may need revision based on additional field and/or mesocosm studies, because our current state of knowledge is based primarily on a small number of observations in the field. Darby et al. have suggested that once snail populations get extremely low, even with more favorable conditions for reproduction and recruitment, populations may be slow to recover (see Chapter 9). Low density snail populations may suffer from depensation (the converse of an allee effect), where mating and reproductive rates are disproportionately low because sparse and scattered individuals have trouble finding mates. This has been observed in low density Florida conch populations, for example (Stoner et al. 2012).

11-4. Recommendation: Conduct a study to document movement and survival of adult snail kites during widespread drying events (water table below ground level) using satellite telemetry. Although the occurrence of drying events cannot be ensured, a multi-year study would be more likely to capture such conditions. Satellite telemetry data can also be used to document movements in response to other changing habitat conditions, including those that influence snail availability, and to identify previously undocumented peripheral habitats. Relating kite

movement patterns to environmental conditions would require assessing snail availability and habitat conditions of the wetland locations documented.

Background—The last large-scale telemetry study was conducted in 1992-1995, which turned out to be a relatively wet period (see Bennetts and Kitchens 1997a). Since the late 1990s, the kite population has decreased in number and conditions in some of its most important habitats have degraded. Kite distribution among wetlands has shifted considerably, and recent satellite telemetry data (Meyer and Kent [2011]) show kites continue to use wetlands not included in the annual kite monitoring survey. Valentine-Darby et al. (1998) analyzed radio telemetry data from 1992-1995 (165 adult kites and 3,361 kite locations) and found that up to ~25% of birds were using peripheral sites at certain times during the year, indicating these areas are important to the kite population. Recent estimates from the work of Meyer et al. indicate the proportion of time spent in peripheral habitats may be higher than observed in the 1990s (Meyer, unpublished data).

Snyder et al. (1989b) monitored eight transmittered adult kites during a "severe" drought period in 1981-1982. They found that seven of eight birds survived the drought, with the fate of the remaining bird unknown. USFWS (1999) stated that more information on movements and distribution during or due to drought conditions was needed. This recommendation was also made in the SEI (2007) report, but that report suggested the main goal should be to document relevant population vital rates. SEI (2007) further stated that the information would be important prior to, during, and after CERP.

Satellite transmitters are much more effective at tracking birds than VHF radios, especially for those movements into previously unidentified locations. VHF radio tracking requires field staff to be physically in the vicinity of the VHF radio to pick up a signal, which means detection depends on the scope and scale of the tracking effort (e.g., flight time and frequency if tracking from aircraft). This is not an issue for signals picked up by satellites. As discussed in Chapter 5, Meyer and Kent (2011) have conducted tracking of kites using satellite transmitters and compared and contrasted the utility of satellite transmitters compared to VHF radios. The GPS-enabled satellite transmitters they have deployed provide 6-8 locations per day per bird with 10- to 15-meter accuracy (K. Meyer, pers. comm.).

11-5. Recommendation: Continue development and validation of the snail kite and apple snail demographic models, and provide linkages between the two models.

Background— The snail kite model currently does not include snail density input, which is essential to understanding how kites respond to the direct and indirect impacts of water level change. More effort should be made to validate the snail kite model output to the empirical data on kites reported yearly. The apple snail model is in early stages of development, still requiring sensitivity analysis and validation via comparison to empirical data. Future plans for the apple snail model are to include data on emergent plant species and SAV, taking advantage of recent developments in remote sensing data (Gann et al. 2012). Eventually, the model should factor in the potential role of predator regulation of apple snail populations, as recent data suggest predators consume a substantial portion of some snail populations (see Chapter 6). The snail kite and apple snail models should be linked.

11-6. Recommendation: Study the conditions that affect mating, reproduction, and dispersal in *Pomacea insularum*. Does *P. insularum* reproduce best under similar conditions as the native Florida apple snail, or, for example, is the species able to exploit a greater range of water depths? The knowledge of such information would assist in controlling this invasive species.

Background— To date, no publications exist on preferred hydrologic conditions for *P. insularum*. Early observations of *P. insularum* on LTOHO indicated they were more likely to occupy deep water habitats, compared to the native snail (P. Darby, UWF, pers. obs.), and anecdotal evidence suggests that the exotic snails can be found in water > 6 feet deep in some lakes (P. Darby, pers. comm.). Other factors that might influence the exotic are temperature tolerances and eutrophication.

11-7. Recommendation: Conduct a native apple snail baseline survey in ENP to determine native apple snail distributions and densities within the park. Key questions include determining whether ENP habitats provide viable densities of apple snails for snail kite foraging. The study should be conducted across various vegetation community types and landscape regions (e.g. Taylor Slough vs. Shark River Slough). Because of the extreme annual shifts in hydrological conditions in ENP, it would be best to conduct this study over multiple years with varying climatic conditions (recommendation from A. Lo Galbo, NPS).

Background— See recommendations for snail monitoring in Chapter 10. Other key questions, in addition to that noted above, include: If ENP habitats provide viable

densities of apple snails for snail kite foraging, what are the conditions that support these snails (e.g., climatic conditions, temporal frequency of climatic conditions, etc.)? Also, how do apple snail densities in ENP differ from other regions of the Everglades that are being used by snail kites for nesting and foraging? It is also of interest to note that ENP contains large tracts of Gulf coast spikerush (*Eleocharis cellulosa*) habitat, which was identified as supporting relatively high densities of snails (Karunaratne et al. 2006) and preferred by kites for foraging (Bennetts et al. 2006). Most of the data in these studies were collected in portions of WCA3A with longer hydroperiods than most of ENP. Sampling in ENP, and comparing these data to those collected in similar plant communities with different hydrologic conditions, would contribute to our understanding of the relative importance of seasonal hydrologic conditions versus vegetation communities on apple snail densities. In preparing a proposal for such a survey, any existing information on apple snails in ENP should first be reviewed. For example, information has been collected by Jeff Kline of ENP, and by Joel Trexler and colleagues, FIU, on 1) apple snail occurrence (aquatic animals, including apple snails, are sampled in $1m^2$ throw traps in spikerush-dominated slough habitats five times a year) and 2) egg cluster counts at a number of sites (including data presented in Bramburger et al. 2012).

11-8. Recommendation: Study 1) the occurrence and prevalence of parasites in native Florida apple snails and exotic apple snails (*Pomacea insularum*), and 2) the occurrence/prevalence of parasitic castration in native apple snails in important kite/snail habitats. To the extent that it is feasible, also study the occurrence and prevalence of parasites in snail kites.

Background— Recent snail samples from WCA3A and LKISS have contained parasites, some of which are purported to cause death in snails (Paul Sharp, FIU, pers. comm.). Parasites may also reduce gonad development in snails, a condition called parasitic castration (Hanning 1979). If the prevalence of parasitic castration is high enough, population-level impacts may affect the density of snails available to snail kites. There is also uncertainty about the types and levels of parasites *P. insularum* may harbor, and, therefore, what concerns may exist for native snails and snail kites.

The snail kite is the definitive host of some trematode parasites (see Chapter 3). Some dead snail kites were known to be infected with the parasites, which probably played a role in their deaths (Cole et al. 1995). We have little information on the impact of parasites on snail kites due to the low probability in recovering freshly dead birds and the difficulty in getting samples from live birds. We realize it may be logistically

challenging to obtain samples from live birds, but there may be opportunities to collect samples while trapping birds for other reasons (e.g., to attach transmitters; see Bennetts and Kitchens 1997a). The degree to which kites would need to be directly sampled (i.e., blood samples) requires further inquiry. Also, P. Sharp (pers. comm., and see Sharp [2008]) has developed a method to detect and possibly identify digenean parasites in snail kite feces, thereby reducing the need to capture birds.

11-9. Recommendation: Conduct a study of apple snail distribution and density and egg cluster production within ridge and slough habitats within WCA3A. The study should occur across multiple years and hydrologic and climatic conditions (recommendation from A. Lo Galbo, NPS [with emphasis on the most pristine areas]). The study should include sawgrass, the sawgrass ecotone, and the habitat gradient that exists from the ecotone out to the center of the deepest portions of juxtaposed slough. If snail kites are also using these habitats, data should also be collected on their use of these habitats for foraging and nesting.

Background— One of the CERP goals is to restore the topographic and habitat gradients associated with historic ridge and slough habitats in portions of WCA3A. With this goal in mind, it would be valuable to know the relative contribution of the different habitat components, including the ecotone, in supporting apple snail populations. As much as possible, an effort should be made to sample across a range of habitat conditions (e.g., relatively pristine ridge and slough and those that have been degraded) to better understand how these habitat types influence apple snail populations. Any existing data on apple snails in these areas should also be examined (e.g., data from Darby et al., Trexler et al., FIU).

11-10. Recommendation: Study whether the invasive exotic *Pomacea insularum* is displacing the native snail in wetlands where it has invaded. A similar recommendation was made by USFWS (2007) and SEI (2007), which suggested research to examine whether the invasive is competing with the native species.

Background— The exotic snail has been documented on LTOHO since around 2001. In recent years reports that native and exotic snails occupy the same sites have emerged (lakes, Kitchens et al. 2008; Everglades, P. Darby, UWF, pers. obs.), giving an opportunity to monitor any displacement of natives by exotics.

11-11. Recommendation: Conduct studies on abiotic (e.g., temperature, water chemistry [e.g., phosphorus and calcium]) and biotic (e.g., food) factors that influence apple snail growth using a combination of field studies, lab studies (to better control conditions and monitor individual growth rates), and possibly *in situ* mesocosm studies.

Background— Relatively few studies have been conducted on Florida apple snail growth. There have been few food preference studies on apple snails (see Chapter 4), and those that have been conducted do not provide enough information to set habitat management and restoration targets. Future studies should include a better representation of the plant and periphyton complexes that exist in wetland units deemed critical to snail kites. Studies should include the effects of nutrient enrichment, especially phosphorus, which can lead to the break-up of periphyton mats and epiphytic periphyton (McCormick et al. 1998, Gaiser et al. 2005). A combination of analytical approaches should be used (e.g., gut content, stable isotopes, fatty acid profiles), since different approaches are more effective at distinguishing between different potential food sources available to snails (e.g., see Lau et al 2008). The studies should also be designed to avoid density dependent growth problems that result in very slow growth rates that make it difficult to show how different diets influence snail growth (see Chapter 4 for details). The results of these studies would also support further development of the apple snail demography model.

11-12. Recommendation: Study the effects of fire on apple snail availability to snail kites. Fire is a management tool that may influence nutrient availability and, consequently, snail growth, as well as habitat structure, which affects both snails and kites. (This recommendation has been slightly modified from that suggested by J. Richards [see Appendix B, comment #12 by Richards in matrix entitled "external comments from peer review form or cover letter").

Background— No information is currently available on the responses of apple snail populations to fire. Such information would assist in understanding the distribution of apple snails, snail growth, and snail population growth. Fires also dramatically alter habitat structure which may, in turn, influence snail kite access to their prey.

11-13. Recommendation: Conduct a field study of the effects of water chemistry on the distribution and abundance of apple snails, and parameterize the developing apple snail demographic model to include water chemistry.

Background— Calcium levels and pH affect apple snail growth and shell integrity (Glass and Darby 2009). Thus far, no effort has been made to incorporate water chemistry as an

explanatory variable in statistical analyses of apple snail density and distribution data. Recent work (e.g., McCormick et al. 2011, Larsen et al. 2011) should be reviewed to determine what other chemical constituents of wetlands water should be studied for potential influence on apple snail populations.

11-14. Recommendation: Conduct additional studies on the effects of predation on apple snail populations (i.e., densities). These studies should include avian and aquatic predation over a range of hydrologic conditions, because apple snails are subject to predation both when wetlands are flooded and under dry down conditions (recommended by A. Lo Galbo, NPS, pers. comm.).

Background— Darby et al (2009) conducted preliminary studies on several aquatic predators (turtles, crayfish and fish). Their study included observations of exotic Mayan cichlids eating apple snails (see Chapter 4 for a summary of the work). These studies included field and laboratory trials, but ultimately the impact of predation was not tied to changes in apple snail densities. Darby et al. (2004) reported predation on snails stranded in dry marsh, but the study included only one site on LKISS that was dry for a few weeks before the study ended. There have been some reports of daily snail kite consumption of apple snails, as summarized in Chapter 7. Large numbers of kites and limpkins have been reported feeding on snails in relatively small areas (Bennetts and Dreitz 1997), but the impact of such heavy predation on the snails has not been reported. For example, it would have been very interesting to know snail densities in WCA2B before and after the kite nesting season in 1995, when there were at least 181 active kite nests in the WCA (Bennetts and Kitchens 1996a). Existing data may provide an opportunity to make estimates of collective predator impacts on apple snail populations, but additional studies are required to understand predator regulation of snail populations across the range of hydrologic conditions and plant communities that influence snail availability.

11-15. Recommendation: Sample soils, water, vegetation / periphyton, apple snails, and as available, snail kites, for copper in order to determine whether there is a negative impact of copper on apple snails or snail kites.

Background— Because agricultural lands that have copper in the soils will be flooded as part of CERP, some concern has been raised that copper will accumulate in apple snails and potentially impact snail kites. Elevated copper levels have been measured in south Florida surface water, sediment, and biota (Schuler et al. 2008). Apple snails are known to accumulate copper and may experience acute and sublethal effects (see Chapter 6 for

details). Schuler et al. (2008) concluded that the potential for ecological risk from chronic exposure to copper was high in areas with applications of copper-containing agrochemicals.

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APPENDIX A: DESCRIPTION OF THE EXTERNAL REVIEW PROCESS

Prior to the external review process, a description of which is the subject of this appendix, the report was reviewed internally by project cooperators with the National Park Service (NPS) and by biologists with the U.S. Fish and Wildlife Service (USFWS). The Pomacea Project proposed the inclusion of the external review process so that the document would benefit from each reviewer's expertise, and to help build a consensus for recommendations in the report. The list of reviewers appears on Page xiv of the document.

The external review was conducted in two phases. In Phase 1, the draft report was reviewed by three experts in the specialties of avian ecology, invertebrate ecology, and wetlands ecology/plant biology. Reviewers provided comments in an electronic comment matrix, a peer review evaluation form, and an optional cover letter. Comments from these reviewers were addressed by incorporating them into the report and/or by responding in the comment matrices. Once all comments were addressed, we produced a revised draft of the document.

The revised draft was then provided to external reviewers for Phase 2 of the external review. While The Pomacea Project, Inc. indicated that we welcomed comments on all sections of the document, we requested their particular attention to Chapters 10 and 11 that contain the recommendations. During Phase 2, the report was reviewed by personnel with the South Florida Water Management District [SFWMD], St. Johns River WMD (SJRWMD), Florida Fish and Wildlife Conservation Commission [FFWCC]), and U.S. Army Corps of Engineers (USACOE). Additionally, a representative of NPS who conducted snail kite research in the past (as a doctoral student at the University of Florida and as a U.S. Geological Survey employee) participated in this phase of the review process. All of the Phase 2 reviewers have dealt with or currently deal with issues related to snail kites, apple snails, and/or wetlands management. Reviewers provided comments in an electronic comment matrix and, if desired, a cover letter. After Phase 2 of the review, The Pomacea Project again addressed and incorporated comments from the reviewers.

Appendix B contains the Phase 1 and Phase 2 review comments, as well as The Pomacea Project's responses to the comments. We received a considerable number of comments from some reviewers. We addressed every comment in the matrix, but not all comments led to our making changes in the report.

APPENDIX B: REVIEW COMMENTS AND HOW THEY WERE ADDRESSED

A description of the external review process for this document was provided in Appendix A. This appendix contains the individual comment matrices, peer review forms from the three species/habitat experts, and cover letters from reviewers when provided. This section is divided into Phase 1 review and Phase 2 review. We considered excluding from this appendix reviewer comments that only pointed out typing mistakes or minor errors, but decided to present each matrix in its entirety. Comment materials are ordered by reviewer, with cover letters (if provided) placed first, followed by peer review forms (for Phase 1 reviewers), and comment matrices. For Phase 1 reviewers, we placed comments (and our responses) from all cover letters in one matrix, which is presented first.

Immediately below are two tables showing the numbers of recommendations in Chapters 10 and 11 as they currently appear, as well as their corresponding numbers in the Phase 1 and 2 drafts. This is provided so the reader can review comments on the particular recommendations if desired. We did not, however, provide a similar key to the remaining chapters and comments due to the length of the report.

Table B-1. Key to Chapter 10 Recommendation Numbers in Final Report and Previous Drafts.

Recommendation # in Final Report	Recommendation # in Phase 2 Draft	Recommendation Line # in Phase 1 Draft *
A-1	A-1	4383
A-2	A-2	4402
A-3	A-3	4414
B-1	B-1	4469
B-2	B-2	4495
B-3	B-5	4573
B-4	D-3	4742
B-5	D-4	4752
B-6	D-5	4767
B-7	D-6	4796
B-8	E-4	4892
C-1	B-3	4523
C-2	C-1	4621
C-3	D-1	4692
C-4	D-7	4807
C-5	E-2	4852
C-6	C-4	4667
C-7	C-6	NA
D-1	A-4	4432

Recommendation # in Final Report	Recommendation # in Phase 2 Draft	Recommendation Line # in Phase 1 Draft *
D-2	E-1	4823
D-3	C-5	4678
D-4	E-3	4869
D-5	D-2	4714
D-6	B-4	4555
D-7	E-5	4906

* Recommendations were not numbered in Phase 1 draft.

Table B-2. Key to Chapter 11 Recommendation Numbers in Final Report and Previous Drafts.

Recommendation # in Final Report	Recommendation # in Phase 2 Draft	Recommendation Line # in Phase 1 Draft *
11-1	11-A-1	4927
11-2	NA	NA
11-3	11-B-2	NA
11-4	11-A-4	4962
11-5	11-A-2	4944
11-6	11-B-5	5057
11-7	11-B-9	5117
11-8	11-B-1	5024
11-9	11-B-8	5103
11-10	11-B-4	5048
11-11	11-B-7	5089
11-12	11-A-9	NA
11-13	11-B-3	5041
11-14	11-B-6	5069
11-15	10-B-7	4598

* Recommendations were not numbered in Phase 1 draft.

PHASE 1 REVIEW

Summary Comments from Three Reviewers

External Comments from Peer Review Form or Cover Letter: Phase 1

Comment Number	Form or Letter # or question #	Comment	Reviewer	Pomacea Project Response
1	Ruehl Form, Question #1	Near the beginning of the report, "the few sentences that drive home the purpose of the report could be in bold to highlight them for readers."	C. Ruehl	We did not make this change.
2	Question #1	…"several of the recommendations substantially overlapped. This section could be streamlined by possibly combining some recommendations to improve communication of goals."	C. Ruehl	We examined this and combined a number of the recommendations. There is some inherent overlap in the recommendations.
3	Question #5	"Some effort should be made to reduce redundancy throughout the report (I made a few suggestions in the line-by-line comments), but acknowledge that some redundancy among sections is warranted to drive home key points."	C. Ruehl	We made an effort, especially in the recommendations section, to address this. We tried to minimize overlap throughout the report, but it is difficult in order to make important points and due to the inherent overlap in the topics.
4	Question #6	"The report is limited by the lack of discussion and recommendations on the role of nutrient enrichment, specifically phosphorus enrichment, on these two species….Recommendations on research concerning phosphorus enrichment at multiple spatial scales should be developed." SEE HIS FORM for more details.	C. Ruehl	We agree that phosphorus could influene many things related to kites and snails (e.g. available foraging habitat for kites, periphyton health important for snails), but there are no studies addressing this directly for the two species. We added some text addressing nutrient enrichment in various places in the report and included a recommendation for research.
5	Question #6	"The report could be bolstered by including more discussion on the importance of snail kites in regulating apple snail populations. I believe these ideas are implied throughout the report, but I could not find them articulated specifically…." SEE HIS FORM for more details.	C. Ruehl	This topic remains unstudied in the existing literature. We agree this is important, although there are many snail populations that are not exposed to snail kite predation (e.g., snails on Wakulla Springs). One of the recommendations in Chapter 11 calls for more research on apple snail predation.
6	Question #7	Snail standing stock (g/m^2) is a better indicator of available food for snail kites than density and is easily attained with length-mass regressions (Ruehl and Trexler 2011 Hydrobiologia 665 1-13). At least one regression has been published for the Florida apple snail (Kushlan et al 1986 Florida Scientist 49 65-79). Obaza and Ruehl (In review) have several regressions for apple snail biomass using aperture length, width, operculum width, length, and total length (as defined in the figure from the report). Size measures should be taken on snails in the field, if they are released, to estimate standing stock available to snail kites.	C. Ruehl	The vast majority of available literature does not use biomass, and our document summarizes the available literature. Cattau et al. (2010) used biomass estimates to compare time energy budgets for kites eating the much larger *P. insularum* (compared to *P. paludosa*). We agree this could be important in time energy budget studies of kites eating a range of sizes of *P. paludosa* . We addressed this suggestion in one of the recommendations in Chapter 10.

External Comments from Peer Review Form or Cover Letter: Phase 1

Comment Number	Form or Letter # or question #	Comment	Reviewer	Pomacea Project Response
7	Question #7	I think it is important to address the impact of the Tamiami trail bridge on apple snail and snail kite populations. This may have been alluded to in one recommendation about the ridge and slough characteristics of WCA 3A, but thought on how the bridge and other planned bridges along this stretch might affect these animals would be fruitful and should be included.	C. Ruehl	We do not agree that it should be included in this report. There is a recommendation in the apple snail section that recommends monitoring over a large scale as well as for individual projecs (e.g., the Tamiami trail bridge). It is outside of the scope of this report to provide a discussion of that and other projects and their potential impacts on kites/snails/habitat.
8	Jennifer Richards Form, Question #2	In this report or a later version/update, I think the authors should include some consideration of snail kite and apple snail habitat in predrainage Everglades, as described in McVoy et al. (2011). One of the radical revisionings in the McVoy et al. book is the argument that wet prairies were not present or abundant in the predrainage Everglades. Some consideration of where the kites and snails were in such a scenario might cause a rethinking of extant habitat....	J. Richards	We discussed this subject (not the McVoy book specifically) with NPS prior to writing the document. We concluded it was beyond the scope of this project, which focuses on kite recovery in the existing network of habitats. The kite population has declined in recent years despite the fact that the network of habitat exists; habitat quality (including snail densities) has declined. As addressed in other comments from this reviewer, we added mention of the McVoy et al. (2011) book. However, it is beyond the scope of this project to include a larger discussion. Additionally, there is very little information (only anecdotal reports) on the occurrence of snail kites (specific habitat types used, exact locations) predrainage. As presented in this report, Sykes (1984) did address available snail kite habitat predrainage in terms of lakes and marshes used. The collection of information on the topic from various sources (including natural history books that briefly report sighting snail kites), including findings on habitat from the McVoy et al. book, could be discussed in a separate effort, or possibly as an update to our current report.

External Comments from Peer Review Form or Cover Letter: Phase 1

Comment Number	Form or Letter # or question #	Comment	Reviewer	Pomacea Project Response
9	Question #2	I also think that the idea that the ecotones between sawgrass and sloughs are the preferred egg-laying habitats for snails needs additional confirmation. The Turner (1996) paper says that preliminary surveys showed few eggs in dense sawgrass, with more in the adjacent edge, so this edge was sampled in that study, using transects that ran parallel to the sawgrass patch. My impression from the current review is that subsequent researchers have selected habitat types in which to sample, following this initial study, in order to compare snail abundance in these habitats, and that selected habitats generally avoided sawgrass patch and ridge interiors. Thus, there does not seem to be published data on snail density in sawgrass. In the Bramburger et al. (2011) swales final report (see below), where egg clusters were counted monthly over a year in 50x2m transects in areas with relatively dense sawgrass, egg masses were found primarily in sawgrass. Slough and wet prairie were not habitat options in the area sampled in this report, but apple snails were still present and using the habitat.	J. Richards	We disagree with the comment that sawgrass-slough ecotones being preferred for oviposition needs further confirmation. It was not just Turner (1996) that had found this; also see Darby et al. (1999), which shows more egg clusters found on the edge than interior sawgrass. Bennetts et al. (1988; which was cited in the 1999 Darby et al. publication) found the same thing. We have made this more clear by citing these 3 reports in Chapter 2 on egg-cluster sampling. Also note that FL apple snail funding priorities have always focused on kite foraging, and kites do not forage in sawgrass unless it is clumped or very low stem density. We realize and agree that snail eggs are found in sawgrass. The findings of Bramburger et al. (2011) that snail egg clusters are found in sawgrass is consistent with past reports and observations. We added mention of the report in Chapter 4's egg-laying section. There are some published density data on snails in other habitats (for sawgrass, see Darby et al. (1999) and Valentine-Darby et al. (2008); for cattail, see Valentine-Darby et al. 2008). We added a brief discussion including these data in Chapter 4.
10	Question #2	Finally, I refer the authors to two final reports on using remote sensing technology to classify and map Everglades vegetation and, in the 2009 project, relate this vegetation to hydrology using the EDEN dataset: Gann and Richards (2009), and Gann, Richards and Biswas (2012).	J. Richards	We looked at the reports and referenced the first in Appendix D and the second in one of the recommendations in Chapter 11 (on snail kite and apple snail models).

External Comments from Peer Review Form or Cover Letter: Phase 1

Comment Number	Form or Letter # or question #	Comment	Reviewer	Pomacea Project Response
11	Question 6-7	"...things that I think are worth considering in the larger research and monitoring context: scale disjunctions: The report provides a good description and is sensitive to the temporal disjunctions in the life cycles of the kite and snail. I do not think that the spatial disjunctions are as clearly considered, although they are mentioned in places. There are two spatial issues. One is from the perspective of individuals. Individual snail kites move over a very large area, whereas individual apple snails move over a much more limited range. With respect to vegetation, therefore, snails could be expected to be much more sensitive to vegetation on the scale at which vegetation varies in the Everglades, i.e., plant community distribution and abundance is more important to snails than to kites." "The other spatial issue is from a population and landscape perspective. Kites have limited geographic distributions. I do not have a clear feeling from the report, however, on the landscape-scale distribution of snails. The report indicates that they are not present in deeper water or shallower water, but are they everywhere in between? If you were modeling snail distribution would it be random (or uniform) throughout potentially available hydrologic habitat? How does this distribution relate to vegetation? The report describes reduced snail densities in water lily slough, but on what scale? Are they present in more open parts of such sloughs, and at what densities? What is their relation to floating periphyton mats (the use of Utricularia/periphyton as a food source in diet experiments suggests some type of use, but what species of Utricularia was this, and what type of periphyton mat?)."	J. Richards	We have addressed some of these points where they were made in the reviewer's comment matrix. We believed that the spatial scales referred to were somewhat obvious concerning the movements of kites vs. snails. However, the vegetation point is one for which we can add some text to address. Regarding the other comment, we added some additional discussion in the report regarding the occurrence of snails (Chapter 4). The reviewer poses many good questions, but data are not available to answer all of them. Some of the questions relate to other researcher's publications/reports, and the details were not provided, so we cannot answer them. We addressed comments/questions in the appropriate places throughout the report, where possible (see the detailed comment matrix for related questions and how they were addressed).
12	Question #7	"In the report, there was no consideration of snail population responses to fire and/or lightning strikes. Dry season fires, which can cover large or small extents, presumably lead to high snail mortality, which should translate to low snail densities in the following year, at least, and depending on snail dispersal and re-colonization, perhaps to low snail density in subsequent years. Wet season (water surface fires), in contrast, might lead to increased snail growth rates through fertilization effects on vegetation. Lightning strikes presumably would lead to snail death in some small area throughout the year. These effects should influence heterogeneity in the landscape-scale snail distribution discussed in the previous paragraph. Thus, some understanding of these effects, and of snail dispersal and re-colonization, should help to understand patterns of snail distribution."	J. Richards	The reviewer raises an interesting question. First, we did not report anything on fire becuase no one has ever addressed this related to snails. Fire certainly influences plant communities, thereby indirectly affecting snails and their distribution. Direct effects might be important if fire burned deposited egg clusters or the substrate where aestivating snails could be found. No data exists on these possibilities. Similarly, there are no data on the other scenarios described (fertilization, etc.). We have added a sentence or two on the influence of fire on habitat and that it could affect snail distribution (in Chapter 4). We have added a recommendation in Chapter 11 regarding a study of the influence of fire on snails.

External Comments from Peer Review Form or Cover Letter: Phase 1

Comment Number	Form or Letter # or question #	Comment	Reviewer	Pomacea Project Response
13	Question #7	"Similarly, what are the cold tolerances for apple snails at different life stages? They become inactive below 13 °C (p. 110, 3312), but do freezes or extended cold-snaps cause massive die-offs, depending on water depth?"	J. Richards	To our knowledge, there is no information available on cold tolerance of FL apple snails at different life stages. We have added some information to the report on cold (and heat) tolerance. Also, anecdotally, PCD/PLV observed snails survive freezing conditions (air temperatures) in a field sampling site in LKISS. In adition, a few snails accidentally left in sampling traps on dry ground in the LKISS area survived two consecutive freezes; once the snails were found they were placed in water and became active. Finally, after freezes on LKISS we saw no indications of dead snails or massive snail die-offs. All of these observations were on adult snails, although some snails were relatively small adults.
14	Question #7	"Snail foraging vs. egg-laying habitats: Snails seem to be able to survive and thrive on SAV, which cannot support air-breathing (p. 116, l. 3490-3494), and such vegetation could not support egg-laying. Snails have to have vegetation or periphyton of some sort to survive and grow, but they do not have to have vegetation to lay eggs, as these can be attached to non-plant substrates. Thus, analysis of habitat requirements for these two activities in relation to vegetation can be uncoupled from each other and, although the requirements for both activities can be met by the same type of vegetation in certain cases, they do not have to be. Understanding snail dietary requirements or limitations seems more critical to understanding snail distributions than understanding egg-laying requirements. How are the dense populations reported on SAVs maintained?"	J. Richards	It's true that SAV does not support egg-laying, but it can support air breathing (see response in main matrix). Regarding the point about snails not needing plants to lay eggs, PCD estimates that greater than 90% of eggs are laid in plants in the WCAs, marshes, and lakes where he has done research. The habitat requirements for egg-laying are well understood and straightforward. Given this, we agree that the gap in this regard is information on snail dietary requirements. Regarding the question of how dense numbers of snails on SAV are maintained, reported high densities in SAV are "snapshots" of snail density and distribution at one point in time. Snails have a considerable ability to move (see Darby et al. 2002 and Chapter 4), so they can move in and out of vegetation types. In nearly every place with SAV that Darby has sampled snails, there are also emergent plant species present. We clarified some sentences in the report to make this more clear, and we added information on snail movements. There is a recommendation in the report on snail food preferences.

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10 May 2012

Ms Patty Valentine-Darby
Director, The Pomacea Project, Inc.
pomaceaproject@cox.net
850-207-5568
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Dear Ms Valentine-Darby,

Thank you for the opportunity to review the draft report entitled "Information synthesis for Florida Apple Snails and Snail Kites and Recommendations for their Adaptive Management." I have thoroughly enjoyed reading and reviewing the literature on snail kites, apple snails, and the many abiotic and biotic factors that influence their demography. Under each question of the review form I provide comments in addition to the detailed comments with references to line numbers in the excel spreadsheet. Please contact me if you require additional comments or clarification on my review.

Sincerely,

Clifton B. Ruehl, Ph.D.
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East Carolina University is a constituent institution of the University of North Carolina. An equal opportunity university.

Peer Review Form for Review of
Information Synthesis for Florida Apple Snails and Snail Kites and Recommendations for their Adaptive Management
March 28, 2012 Draft

Thank you for agreeing to provide your experience and expertise in evaluating this report. Your efforts will enhance the quality of the report and its usefulness to the National Park Service, other federal and state agencies with a role in the conservation of the snail kite and the Florida apple snail, and the general public. Your review ranking and comments will be provided to the authors and will be included in an appendix of the report. Please note that your name will not remain confidential.

I GIVE PERMISSION TO INCLUDE MY NAME ON REVIEWS PROVIDED TO THE AUTHORS AND IN THE APPENDIX OF THE REPORT (WHICH WILL CONTAIN MY COMMENTS)

Signed by _____CLIFTON B. RUEHL_____

1. Is the project purpose clearly presented and does the report's organization suit the purpose?

*** Highlight or circle:**
Strongly disagree ↔ Strongly agree*
1 2 3 4 5

Additional Comments (if any):

The purpose was clearly stated in the first several pages of the report. The few sentences that drive home this purpose could be in bold to highlight them for readers. I liked the organization of the report. The recommendations section was very through. Having species-specific recommendations and more general recommendations is important because these species have very different life histories. However, several of the recommendations substantially overlapped. This section could be streamlined by possibly combining some recommendations to improve communication of goals.

2. Is the literature review portion of the report adequate (i.e., appropriately covered the published/gray literature available, addressed the relevant topics) given the purpose of the report?

Strongly disagree ↔ Strongly agree*
1 2 3 4 5

Additional Comments (if any):

Generally, the literature cited was comprehensive. I added relevant in the line-by-line comments.

3. Does the report present significant or new findings, or present the information in a significant or new way?

Strongly disagree ↔ Strongly agree*

1 2 3 4 5

Additional Comments (if any):

The report integrates and reviews the literature on snail kites and the literature on apple snails, which is a novel approach for these two species. Integrating these two disparate literatures is critical to understanding the factors affecting kites and snails for effective management because of the tight trophic linkage (kites depend on snails) between them. This report is a critical step forward in the management of these species.

4. Are the conclusions and recommendations reasonable and supported by the data and other evidence?

Strongly disagree ↔ Strongly agree*

1 2 3 4 5

Additional Comments (if any):

Yes, the conclusions and recommendations are well supported. There is a significant need for concurrent data on snail kite and apple snail demographic and distributional data to facilitate management in the midst of restoration activities like CERP.

5. Overall, is the information well-presented, logical, and understandable?

Strongly disagree ↔ Strongly agree*

1 2 3 4 5

Additional Comments (if any):

The report provides a clear message that data on the hydrology of local habitats, snail kite distribution, and apple snail distribution need to be collected together and that much research has been done on kites, while research on apples snails has lagged. Some effort should be made to reduce redundancy throughout the report (I made a few suggestions in the line-by-line comments), but acknowledge that some redundancy among sections is warranted to drive home key points.

6. Please comment on the strengths and limitations of the overall product and its potential usefulness to managers and others.

Strongly disagree ↔ Strongly agree*

1 2 3 4 5

Product is useful to managers & others?

This report will be useful to managers by establishing a roadmap for future research to inform management decisions and goals for snail kites and apple snails. It addresses the key challenges with this effort and provides insight into how those challenges can be met through collaborative research efforts among kite biologists and snail biologists.

Comments on strengths and limitations:

The strength of this report is that it provides a central repository of prior work on both the snail kite and the apple snail, develops specific research goals, and outlines a plan to reach those goals as a basis for an adaptive management plan of these two species that works in conjunction with the Multi-Species Recovery Plan. Central to the goal are improved data on the abiotic (hydrology) and biotic (predation) factors driving the distribution and abundance of snail kites and apple snails, which is clearly articulated in the report. I identified two limitations.

1. The report is limited by the lack of discussion and recommendations on the role of nutrient enrichment, specifically phosphorus enrichment, on these two species. Phosphorus enrichment alters ecosystems in characteristic ways that could have positive (e.g., improve resource quality) and negative (reduce periphyton biomass, alter macrophyte abundance and composition) effects on apple snails and indirectly snail kites. Phosphorus enrichment occurs over much of the snail kites distribution. It will continue to be a factor that shapes the ecosystems where these animals live. Recommendations on research concerning phosphorus enrichment at multiple spatial scales should be developed.

As an example, phosphorus enrichment has altered much of the northern Everglades (WCA 1, WCA 2), but has not affected southern portions of the Everglades (ENP) as much. Although many variables change along this latitudinal gradient, phosphorous enrichment alters the species composition of emergent vegetation, submerged vegetation, periphyton standing crop, and macroinvertebrates including snails (Gaiser et al 2005 JEQ 34 717-723, McCormick et al 2004 Hydrobiologia 529 113-132, Liston et al 2008 Wetlands 28 686-694, Ruehl dissertation http://digitalcommons.fiu.edu/etd/266/). Gathering data on phosphorus concentrations in periphyton and floc in the areas where snails and snail kites are monitored will provide insight into snail food quality over a large spatial scale.

At a local scale, snail kites (and other wading birds) facilitate periphyton growth by releasing their excrement. This is particularly important around roosts and nests where birds congregate and spend time. Therefore, kites could conceivably increase snail standing stock (g/m^2) in areas where they roost through the deposition of nutrient rich waste that stimulates periphyton growth and improves snail food quality (C:P ratio). Quantifying these indirect effects might reveal important insight into the factors controlling snail population sizes.

2. The report could be bolstered by including more discussion on the importance of snail kites in regulating apple snail populations. I believe these ideas are implied throughout the report, but I could not find them articulated specifically. A prominent piece of the report focuses on collecting data on kites and snails at the same locations during the same periods at relevant spatial scales. Such data will enable time-series analysis (Turchin 2003, "Complex population dynamics") that could yield important information on the factors driving population growth for both species and guide refinement of prediction models like EVERKITE. Analyses might reveal that snail kites and snails cycle something like the lynx-hare cycle. Time lags would probably be important because kites live so much longer than snails. For example, the boom in kites during the mid to late 90's might have been because several years before that (i.e., late 80's early 90's) snails were very abundant leading to a lot of kite recruitment, that in turn decimated snail populations and the kite population subsequently crashed. Environmental conditions could have facilitated snail capture by kites at the same time aiding in the over-exploitation of snail populations in WCA 3A by kites. Therefore, specifically addressing the interdependence of snail kite and apple snail population dynamics could help explain fluctuations in population size of both species.

7. Other comments?

1. Snail standing stock (g/m^2) is a better indicator of available food for snail kites than density and is easily attained with length-mass regressions (Ruehl and Trexler 2011 Hydrobiologia 665 1-13). At least one regression has been published for the Florida apple snail (Kushlan et al 1986 Florida Scientist 49 65-79). Obaza and Ruehl (In review) have several regressions for apple snail biomass using aperture length, width, operculum width, length, and total length (as defined in the figure from the report). Size measures should be taken on snails in the field, if they are released, to estimate standing stock available to snail kites.

2. I think it is important to address the impact of the Tamiami trail bridge on apple snail and snail kite populations. This may have been alluded to in one recommendation about the ridge and slough characteristics of WCA 3A, but thought on how the bridge and other planned bridges along this stretch might affect these animals would be fruitful and should be included.

3. Recommendations on hydrology represent a step forward. Fine-scale water depth data is important because slight changes in topography have big implications for aquatic animals and birds feeding on them. Including recession and ascension rates in recommendations addresses an important component of wetland management.

External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
1	iv	The first full sentence on this page is awkward. The idea is an important one for the review and should be stated clearly.	Cliff Ruehl	Edited wording.
2	x	Acronyms start on xvii in this version	Cliff Ruehl	Will correct. This error has to do with automatic changes made when creating the pdf.
3	line 361-365	I cannot follow what this sentence means	Cliff Ruehl	We clarified the sentence.
4	line 389	missing the word "events" or similar before sampling	Cliff Ruehl	Agree. Fixed (but it's after "sampling").
5	line 879	This sentence seems redundant with line 872	Cliff Ruehl	Sentence revised to delete redundancy.
6	line 915	Missing the open paraenthesis for Sykes 1984 citation	Cliff Ruehl	Fixed.
7	line 1017	Paul Sharp's dissertation is mentioned. Prehaps elaborate on his findings a bit. I seem to recall that he found high loads of parasites in all the snail species he studied	Cliff Ruehl	Additional details have been added.
8	line 1311	Need to cite Lodge et al 1987 American Malacological Bulletin 1, 73-84. For a general distribution paper might consider citing: Mckillop and Harrison 1972 Canadian Journal of Zoology 50, 1433-1445	Cliff Ruehl	Citations added to this paragraph as recommended.
9	line 1425	I think a more interesting statement about how temperature, food, and water depth influence Florida apple snails is appropriate as I am sure these abiotic factors do impact them. The real question is how and to what extent	Cliff Ruehl	We revised the section to address the comment. Also, we added some additional aspects to the recommendations in Chapter 11 to address the comment.
10	line 2258	replace "had found" with "found"	Cliff Ruehl	Done.
11	line 2336-2342	Might want to also compare the Everglades to the seasonal fluctuations in the karst wetlands in Mexico and Belize. For a description see: Rejmankova et al. 1996 Internationale Revue der GesamtenHydrobiologie 81 223-252 and her other works	Cliff Ruehl	We believe that this is getting away from the main point of these sentences, so we did not make this change. However, it would be interesting to look at the fluctuations in wetland systems in other countries where snail kites are found (and kite research has been done), but this is outside of the scope for the current project.
12	line 2369	It might be nice to remind the reader what Shat is here	Cliff Ruehl	Done.

External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
13	line 2481-2484	Please provide F statistics for these P values	Cliff Ruehl	We were unable to provide F statistics in the Chapter 5 discussion because they were not provided in the Cattau et al. (2008) report.
14	line 2258	Also important to mention nutrients here	Cliff Ruehl	We belive this comment was made in reference to line 2558. However, we did not make the suggested change because the subject of these sentences is predation of kite nests (and nutrients would play a small role or no role in that).
15	line 2716	Should cite a general reference for meta-analysis like Scheiner and Gurevitch book "Design and analysis of ecological experiements"	Cliff Ruehl	Done; a citation and definition was added.
16	line 2892	Where the greater Everglades ecosystem has this occurred? Name the EAA, WCA 1, edges of LNWR, WCA2A etc…	Cliff Ruehl	The text on this page was not changed to address the comment; the sentence in brackets was really an aside, so we don't want to add additional information here. However, we addressed the comment by adding text to the end of Chapter 3 that discusses impacts to snail kite habitat in FL.
17	line 2921-2923	This sentence seems redundant with the sentences preceding it	Cliff Ruehl	Agree; section was edited.
18	line 3157-3159	Cite Trexler et al. 2005 Oecologia 145 140-152	Cliff Ruehl	Citation was added as recommended.
19	line 3311	Is this temperature of the water or air	Cliff Ruehl	We clarified this paragraph to address the comment.
20	line 3356	Elaborate on why nutrient enrichment is bad. For example, P enrichment causes perihyton mat to fall apart	Cliff Ruehl	A sentence has been added stating that P enrichment can cause periphyton mats to fall apart. Note that the effects of eutrification on FL apple snails is an unstudied area.
21	line 3383-3396	This paragraph suggests that factors other than food limitation limit individual growth of snails when they occur in high density. What are some of these processes if this is correct?	Cliff Ruehl	This is what the Conner et al. study concluded. There is literature for other snails describing these mechanisms, but not for the FL apple snail. We cited a publication for other snails, and pointed out the mechanism is not known for the FL apple snail.
22	line 3564	delete "had"	Cliff Ruehl	Done.
23	line 3795	delete on space before the sentence starting with "Darby et al..."	Cliff Ruehl	This should have been the start of a new paragraph; saving as a pdf created this change. Word version is fine.

External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
24	line 3936	Could cite Connell intermdediate disturbance hypothesis here	Cliff Ruehl	Although Mooij et al. (2007) did not mention the hypothesis, we added the Connell citation.
25	line 4007	What about including data on biotic factors like aquatic predator density, snail kite density, other invertebrates that compete with apple snails. This gets at both top down and bottom up processes	Cliff Ruehl	These are very desirable factors to incorporate; unfortunately the model is in relatively early stages of development and their inclusion is not possible at this time (hydrology and temperature parameters need to be evaluated first). In some cases (e.g., with snail competitors) there are few data upon which we can parameterize the model to factor in these biotic factors. We will add a statement that in the future, attempts should be made to include such factors.
26	line 4056	delete "d" in "estimated"	Cliff Ruehl	Done.
27	line 4094-4105	This paragraph was a little confusing. If snails typically senese in March and June, which year class is reproducing in late summer? Is it the young of the year or adults that did not die? Do some wait to senese until they have reproduced?	Cliff Ruehl	Based on the conditions reported in Darby et al. (2008), snails do not senesce until after peak reproduction, which typically means sometime after May or June. We modified the paragraph to clarify which snails would be reproducing in summer after a dry down.
28	line 4491-4493	Please provide more detail about how these actions will impact the ridge and slough habitat	Cliff Ruehl	Specific details were not provided to us.
29	line 4495	I like the focus on the rate of change in depth	Cliff Ruehl	Nothing to address.
30	line 4555	This is a good recommendation. Local topography is important, but also local rainfall can influence depth too on the order of days. Yes, avoiding terms like drought that means different things to different people is good.	Cliff Ruehl	No action needed.
31	line 4692	This is probably one of the most critical recommendations. I these data should be collected with an eye for studying population cycles or synchrony between apple snails and snail kites; something like the lynx-hare cycle only the lag time could be much greater because of the great difference in life-length between snail kites and apple snails	Cliff Ruehl	We agree. We have added a sentence to the recommendation background to acknowledge this point.
32	line 4735	Who is being informed?	Cliff Ruehl	Text has been clarified.

External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
33	line 4752	Either here or another recommendation should be made about a recession and ascension rate of water to optimize snail production	Cliff Ruehl	Rates may be important components, but based on the available information at this time, it does not appear that rates are important to egg laying as long as the desirable depth range is available. This range should, however, be verified by more work, and we have added it as part of a new research recommendation (Chapter 11).
34	line 4835	How will these data be integrated? Will models be used, time-series analysis as data become available?	Cliff Ruehl	We revised the recommendation to be more clear. Studies/data could be integrated at various levels (e.g., in kite/snail simulation models, in statistical analyses, and in data collection efforts).
35	line 4852	This recommendation is also good because it provides much production information on snail kites in relation to snails. These data could be used in models. Development of time-series data for both snails and kites is critical and this recommendation will facilitate that like that one in line 4692	Cliff Ruehl	We agree, and we have added one sentence to the background information associated with the recommendation.
36	line 4863	Is density put here twice?	Cliff Ruehl	Yes, the first "density" referred to habitat. However, we will delete it to avoid confusion.
37	Line 4872	Joel Trexler has data on apple snail density that could also be used	Cliff Ruehl	We contacted Joel Trexler to learn about his information on apple snails. We added mention of the data in our recommendation. However, note that Dr. Trexler indicated the purpose of his study is not to quantify snail densities, and to do so would require more samples than are taken.
38	line 4944	This is a great recommendation. Clearly resources are important to understanding snail kite demography. As stated above, kite density should be included in apple snail models	Cliff Ruehl	We added that future work on the apple snail model should include the influence of predators such as the kite.
39	line 4954	Understanding age specific mortality is also important. The spatial distribution of mortality should also be considered. Satellite telemetry might be better than radio telemetry for reasons mentioned elsewhere in the report	Cliff Ruehl	Comments incorporated in the recommendation.
40	line 5024	One thought that came to mind with this recommendation is who are the definitive hosts for the parasites in apple snails. Snail kites seem like a likely candidate. Perhaps a parallel study of parasite load in snail kites?	Cliff Ruehl	The snail kite background chapter (3) has a section on parasites in snail kites. We added a recommendation to the report (in Chapter 11) addressing a parasite study in kites.

External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
41	line 5033	Do you mean that this could be happening because of an Allee effect? Positive population growth with increasing population size. For example, apple snails can't find mates at really low densities but it gets easier with increasing density.	Cliff Ruehl	Yes, that is what this paragraph is saying. We added a reference to another publication in the recommendation background.
42	line 5041	This might only be a problem in the middle of LNWR, but should see: McCormick et al. 2011 Critical Reviews in Environmental Science and Technology 41 28-63, Larsen et al. 2011 Critical Reviews in Environmental Science and Technology 41 344-381, James et al. 2011 Critical Reviews in Environmental Science and Technology 41 576-607	Cliff Ruehl	Glass (2007) reported pH ranged from 6.7-8.8 and calcium 16-133 mg/l in WCA3A.; based on her work and others, snails likely respond to these gradients. We added citation of the papers mentioned here in the recommendation background in the context of general questions about water chemisty influences.
43	line 5069	Predation is likely a very important aspect of snail demography. Therefore, this is an important recommendation	Cliff Ruehl	No action needed.
44	line 5089	I like this recommendation in principle but I am not sure isotopic work will provide the resolution for separating among periphyton constituents. Might want to consider using phosphlipid fatty acid analyses or DNA of stomach contents or fecal material to identify diet	Cliff Ruehl	We spoke with the reviewer and revised the recommendation accordingly (and added additional information to the recommendation background).
45	line 5089	Nutrient enrichment should also be considered here; specifically, P enrichment	Cliff Ruehl	We added inclusion of phosphorus enrichment into the recommendation.
46	line 5103	Joel Trexler has data on apple snail density that could used for wet prairies throughout WCA but it is only a start as their protocol does not include as many traps as the Darby protocol. These data could be used as a first pass to better direct resources. CERP MAP data is also an excellent source to establish snail densities throughout the Everglades. Analyses could be done to determine if the existing data are adequate	Cliff Ruehl	We have added mention of the Trexler data set in the recommendation. Dr. Trexler has data for some sites in WCA3 and ENP dating back to 1996 in spikerush-dominated habitat. Captured apple snails are recorded, but snails are not the purpose of the work. Dr. Trexler noted that to obtain a good snail density estimate, additional samples should be taken. Darby is currently collecting data from over 20 sites in WCA3A, specifically to address snail abundance.

External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
47	line 5117	Joel Trexler and has data on apple snail density that could used for wet prairies throughout ENP but it is only a start as their protocol does not include as many traps as the Darby protocol. These data could be used as a first pass to better direct resources. CERP MAP is another excellent source for data on apple snail density throughout the system as a point of departure for developing further sampling protocols. Analyses of existing data should probably be done to determine if those data are adequate and what data need to be collected.	Cliff Ruehl	We have added mention of the Trexler data set, as well as other sources of information, in the recommendation. Dr. Trexler has data for some sites in ENP dating back to 1996 in spikerush-dominated habitat. Captured apple snails are recorded, but snails are not the purpose of the work. Dr. Trexler noted that to obtain a good snail density estimate, additional samples should be taken.

R. Borkhataria

Peer Review Form for Review of
Information Synthesis for Florida Apple Snails and Snail Kites and Recommendations for their Adaptive Management
March 28, 2012 Draft

Thank you for agreeing to provide your experience and expertise in evaluating this report. Your efforts will enhance the quality of the report and its usefulness to the National Park Service, other federal and state agencies with a role in the conservation of the snail kite and the Florida apple snail, and the general public. Your review ranking and comments will be provided to the authors and will be included in an appendix of the report. Please note that your name will not remain confidential.

I GIVE PERMISSION TO INCLUDE MY NAME ON REVIEWS PROVIDED TO THE AUTHORS AND IN THE APPENDIX OF THE REPORT (WHICH WILL CONTAIN MY COMMENTS)

Signed by : Rama Borkhataria

1. Is the project purpose clearly presented and does the report's organization suit the purpose?

*** Highlight or circle:**
Strongly disagree ↔ Strongly agree*
1 2 3 4 **5**

Additional Comments (if any):

This document is ambitious and well-organized. The authors did a good job of identifying the relevant questions concerning snail kite and apple snail research and the disconnect between research and effective conservation and recovery for the snail kite.

2. Is the literature review portion of the report adequate (i.e., appropriately covered the published/gray literature available, addressed the relevant topics) given the purpose of the report?

Strongly disagree ↔ Strongly agree*
1 2 3 4 **5**

Additional Comments (if any):

The authors provided a comprehensive review of existing literature and addressed the relevant topics.

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3. Does the report present significant or new findings, or present the information in a significant or new way?

Strongly disagree ↔ Strongly agree*

1 2 3 4 **5**

Additional Comments (if any):

This document stresses the importance of examining population trends in both snail kites and apple snails and linking the demography of the two species. Despite the dependence of the kite on the apple snail, the report illustrates the paucity of empirical information on the relationship between snail kite movements, survival, and productivity and apple snail densities. Connecting the species through population and spatially explicit habitat models represents a significant advancement in snail kite research.

4. Are the conclusions and recommendations reasonable and supported by the data and other evidence?

Strongly disagree ↔ Strongly agree*

1 2 3 4 **5**

Additional Comments (if any):

5. Overall, is the information well-presented, logical, and understandable?

Strongly disagree ↔ Strongly agree*

1 2 3 **4** 5

Additional Comments (if any):

Due to the range and volume of information presented in the report, there were a few sections that were a little confusing, but overall it was logical and understandable.

6. Please comment on the strengths and limitations of the overall product and its potential usefulness to managers and others.

Strongly disagree ↔ Strongly agree*

1 2 3 4 **5**

Product is useful to managers & others?

Comments on strengths and limitations:

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The report was understandable and informative and presented a lot of recently acquired information on the relationships between snail kites and apple snails. It also clearly points out where data are lacking and provides a range of recommendations for addressing these gaps. The division of information into relevant chapters will be helpful for managers that are interested in specific aspects of snail kite and/or apple snail demography. Despite the enormous amount of information presented, overall the document read well and was consistently interesting.

7. Other comments?

Authors should be commended on a job well done.

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External Peer Review Comments

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
1	1, 1, 20	I think it would be helpful to the reader for you to list the specific references.	Rena Borkhataria	We examined how to make this more descriptive (e.g., by adding "see citations in literature cited by..." or by listing some of them in an "e.g., ..." statement); however, listing all of the many citations would be cumbersome and distracting.
2	1, 1, 21	Same as above.	Rena Borkhataria	Response same as above.
3	1, 2, 30-45	I like the way you have framed the questions and established the relevance of this report.	Rena Borkhataria	Great. No change needed.
4	1, 4, 98	Recommendations will not be made here because...? Very brief explanation of command and control pathology along with the reference to Holling and Meffe would be nice.	Rena Borkhataria	We clarified the text.
5	Figure 2-1	This map could be better. The labels are hard to read and it lacks a scale (and north arrow).	Rena Borkhataria	We have improved this figure to make it more readable. Also, a scale has been added to the first figure of the report (which is now 1-1).
6	Chapter 2, pages 8-10	A timeline or some sort of figure or table depicting the era, researchers, water levels, and the type of work being done would be helpful.	Rena Borkhataria	We agree that this would be nice to have; we'll create such a figure if time allows. This information is also expanded on in Chapters 5 and 6.
7	2, 12, 323	What are the other categories of nest failure?	Rena Borkhataria	Have added the other categories of failure from the monitoring reports.
8	General	Consider including a map of the region depicting the various lakes, wetlands, and water conservation areas.	Rena Borkhataria	We added a map in Chapter 1 (Figure 1-1).
9	3, 30-31, 872-885	Consider reversing the order of these 2 paragraphs.	Rena Borkhataria	Edited as suggested.
10	3, 37, 1077	Spelled "Corbett" not Corbitt (elsewhere in document also)	Rena Borkhataria	Corrected.
11	3, 38, 1106	Figure 3-7 needs further explanation. The discrepancy between actual counts (squares) and population estimates (circles) is hard to interpret in this context.	Rena Borkhataria	We added a few minor clarifications to this paragraph (e.g., that we are referring to a portion of the figure [the squares]). In Chapter 5 of the report we provide a bigger discussion of the figure, and the reference (in Chapter 3) to this discussion is now more obvious. A discussion of Figure 3-7 could have gone in either Chapter 3 or 5, but it fits best in Chapter 5.

External Peer Review Comments

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
12	4, 50, 1457	Do shifts in the timing of oviposition due to hydrology affect juvenile survival/recruitment?	Rena Borkhataria	This is a good question. The shifts in peak oviposition may influence juvenile growth and survival, but unfortunately, there are few data on the subject. The question warrants further investigation and we have added a recommendation in Chapter 11 that includes this.
13	5, 68, 2021	What year were 372 birds supported?	Rena Borkhataria	It was 1985; clarified the text.
14	5, 68, 2026	As you have mentioned this area specifically, it might be worth noting that snail kites have continued to use this roost site consistently over the years, although in varying numbers and with many fewer at the current time.	Rena Borkhataria	We agree. We contacted Marybeth Morrison to obtain information on the roost counts she performs and the type of information collected. We added a few sentences to the text in Chapter 5 and to the background material of the roost recommendation in Chapter 11.
15	5, 77, 2305	Insert "on" ("based on")	Rena Borkhataria	This has been fixed.
16	5, 89, 2690	Should be "kite" or "kite's", not "kites"	Rena Borkhataria	This has been fixed.
17	6, 117, 3512	Need closing parenthesis	Rena Borkhataria	This has been fixed.
18	7, 126, 3757	Should probably be "caution against"	Rena Borkhataria	This has been fixed.
19	7, 128, 3833-3834	This sentence is confusing. Check for clarity.	Rena Borkhataria	Have clarified the sentence.
20	9, 140, 4131-4133	Check the sense of this sentence.	Rena Borkhataria	Sentence has been edited.
21	9, 141, 4174	In which year or years was recruitment in WCA3A zero?	Rena Borkhataria	Done, have added info.
22	10, 163, 4823-4832	A snail kite/apple snail working group that meets annually to discuss the past year's research and population trends would be helpful. The FWS organizes a wood stork working group meeting annually that is attended by agency personnel and researchers from across the southeast that is invaluable for fostering collaboration and keeping everyone informed on issues relating to wood stork status and recovery.	Rena Borkhataria	No change needed, but we discussed the wood stork group with the commenter and added a few details on the group as an example in the recommendation.

External Peer Review Comments

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
23	11, 170, 5014-5020	I think this is an especially important recommendation. Furthermore, some index of apple snail production or snail habitat quality in the previous year should be taken into account.	Rena Borkhataria	We agree with the intent of your comment (although the data are not available), but we have removed this recommendation from the report. The topic of this recommendation is now addressed in Chpater 9.
24	11, 170, 5033-5039	Understanding apple snail recovery times under a range of hydrological conditions seems essential.	Rena Borkhataria	No change needed.

J. Richards

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I GIVE PERMISSION TO INCLUDE MY NAME ON REVIEWS PROVIDED TO THE AUTHORS AND IN THE APPENDIX OF THE REPORT (WHICH WILL CONTAIN MY COMMENTS)

Signed by _JENNIFER H. RICHARDS _____ Jennifer H. Richards

1. Is the project purpose clearly presented and does the report's organization suit the purpose?

*** Highlight or circle:**
Strongly disagree ↔ Strongly agree*
1 2 3 4 5

Additional Comments (if any):

The purpose is clearly outlined in the first chapter, and the authors include introductory paragraphs in the other chapters that summarize what is to come in that chapter and reference related information in other chapters. This seems repetitive at times, but I think it makes the report easy for anyone coming in and reading a single topic to see where that topic fits into the larger picture and to easily find related information in the document.

2. Is the literature review portion of the report adequate (i.e., appropriately covered the published/gray literature available, addressed the relevant topics) given the purpose of the report?

Strongly disagree ↔ Strongly agree*
1 2 3 4 5

Additional Comments (if any):

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In this report or a later version/update, I think the authors should include some consideration of snail kite and apple snail habitat in predrainage Everglades, as described in McVoy et al. (2011). One of the radical revisionings in the McVoy et al. book is the argument that wet prairies were not present or abundant in the predrainage Everglades. Some consideration of where the kites and snails were in such a scenario might cause a rethinking of extant habitat. Maybe the lake populations were larger or more important, or maybe kite and snail use of the Everglades region is actually different from what we currently think. For example, Gann et al. (2012) used WorldView 2 satellite imagery, which has a 2x2m pixel, to map vegetation in ridge and slough and wet prairie habitats in WCA3. They found that the sawgrass ridges had more heterogeneous vegetation than is typically described. The ridges had small patches of broad-leaved plants in them, as well as shrubs. Maybe such places provide small "diners" for kites or are important nurseries for snails.

I also think that the idea that the ecotones between sawgrass and sloughs are the preferred egg-laying habitats for snails needs additional confirmation. The Turner (1996) paper says that preliminary surveys showed few eggs in dense sawgrass, with more in the adjacent edge, so this edge was sampled in that study, using transects that ran parallel to the sawgrass patch. My impression from the current review is that subsequent researchers have selected habitat types in which to sample, following this initial study, in order to compare snail abundance in these habitats, and that selected habitats generally avoided sawgrass patch and ridge interiors. Thus, there does not seem to be published data on snail density in sawgrass. In the Bramburger et al. (2011) swales final report (see below), where egg clusters were counted monthly over a year in 50x2m transects in areas with relatively dense sawgrass, egg masses were found primarily in sawgrass. Slough and wet prairie were not habitat options in the area sampled in this report, but apple snails were still present and using the habitat.

I will attach the Final Report of the Bramburger et al. project in ENP that included data on apple snail egg cluster frequency in different plant communities; this report also had descriptions of the plant communities sampled, as well as other consumers, soil and water nutrients and periphyton data.

Bramburger, A.J., E.E. Gaiser, J.H. Richards, J.M. Hoch, E.R. Sokol, J.C. Trexler and L.J. Scinto. 2011. Water quality, soils and ecological effect of pilot spreader swales along the Tamimai Trail in Everglades National Park: Baseline Monitoring Report. CA H5000060104 for Department of the Interior National Park Service, South Florida Natural Resources Center and South Florida/Caribbean Cooperative Ecosystem Studies Unit. 77 pp. plus snail egg mass protocol, 3 pp.

Finally, I refer the authors to two final reports on using remote sensing technology to classify and map Everglades vegetation and, in the 2009 project, relate this vegetation to hydrology using the EDEN dataset. I provide an orientation to these reports below.

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1. Gann and Richards, 2009:
   Gann, D. and J.H. Richards. 2009. Determine the Effectiveness of Plant Communities Classification from Satellite Imagery for the Greater Everglades Freshwater Wetlands &Community Abundance, Distribution and Hydroperiod Analysis for WCA 2A. Final Report for PO#4500033517, South Florida Water Management District. 278 pp.

   ftp://gisrsftp.fiu.edu/Share/RECOVER/4500033517_finalReport.pdf

   This research had rather diverse objectives. The first part (Section 1) was to explore using remote sensing data from Landsat images (30x30m pixels) to map vegetation in WCA 2A and in ENP. The work in the two regions involved very different questions and worked with different reference data. The general conclusion was that it was possible to map vegetation at this scale with Landsat images, and the report discusses the advantages and limitations of this approach. We created a vegetation map of WCA 2A at the 30x30m Landsat resolution and compared that to the CERP vegetation map from photointerpretation of aerial imagery at the 50x50m resolution. We have since extended this work to include WCA 1, so that we have a Landsat vegetation map of these two regions; the limitation of this map is that we were using the CERP map as our reference, so we were mapping from 2003 imagery, and the final product thus cannot have a design-based post-classification accuracy assessment (i.e., we can only compare our results to the CERP map results, which are mapped from aerial photos taken in 2003; because we cannot go back in time, we cannot ground-truth our map—although we might be able to get some estimate using the original aerial photography). The Section 1 problem in ENP was how to relate very high-resolution ground data to the coarser Landsat images; this exercise was informative but did not involve mapping. Thus, Section 1 of this report is of interest for monitoring snail kites and snails because it shows that it is possible to get estimates across the Everglades region for abundances and distributions of the different communities that have been identified as kite and snail habitat.

   The second part of this report (Section 2) is of interest to the Pomacea project because it dealt with relating hydrology to vegetation type. This part of the report included a review of the literature on herbaceous and woody Everglades wetland plant communities. Richards and Gann (2008) reviewed data on marsh species, whereas this report includes data on marsh communities, as well as on woody communities; woody species/communities were not reviewed in the prior report. Of greater interest to the Pomacea project is that in the 2009 report we estimated vegetation hydrologic tolerances from our data for WCA 2A, thus connecting the EDEN hydrologic data to the vegetation data. Making this connection is not straightforward, as the EDEN grid is at 400x400m, whereas vegetation varies at a much finer scale. Thus, our approach was to use the HAED points (the location in each EDEN grid where elevation was measured) and to determine the vegetation classification at that point from our map, the CERP map, and field data (when available). We could then use adjust the EDEN cell data to that point location in order to get water depth at that point, then relate that depth to the plant community at that point. The data from this section provides a very robust picture of

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plant community tolerances. We also created a number of different ways to look at hydrologic parameters, given the temporal extent of the EDEN dataset; we think these are more biologically relevant than annual averages of hydroperiod.

Since writing the 2009 report, we have incorporated data from WCA 1 into this hydrology/vegetation analysis. And we hope to have a manuscript from this submitted within the next month. When we have submitted it, we will send you a copy.

2. Gann, Richards and Biswas, 2012:
Gann, Daniel, Jennifer Richards and Himadri Biswas. 2012. Synthesis Report for Consulting Services to Determine the Effectiveness of Vegetation Classification Using WorldView 2 Satellite Data for the Greater Everglades. South Florida Water Management District, 62 pp.

ftp://gisrsftp.fiu.edu/Share/RECOVER/4500058664_synthesisReport.pdf

This report deals with using WorldView 2 (WV2) satellite data, which has a 2x2m pixel resolution, to classify vegetation in the Everglades region. The report also investigates relating the WV2 data to Landsat data and considers the effects of scale on classification results. The fine-grained resolution of the WV2 data provides detail that would be relevant to the apple snail habitat. It was from these images that we came to appreciate the heterogeneity of sawgrass ridges (e.g., see Figure 6, p. 53, in the report). This report shows the level of detail about habitat that is available from these images and might be useful to consider in kite and snail habitat monitoring.

3. Does the report present significant or new findings, or present the information in a significant or new way?

Strongly disagree ↔ Strongly agree*
1 2 3 4 5

Additional Comments (if any):

The combination of reviewing the kite literature and the apple snail literature in one place makes the relevance of and information gaps between the two clear.

4. Are the conclusions and recommendations reasonable and supported by the data and other evidence?

Strongly disagree ↔ Strongly agree*
1 2 3 4 5

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Additional Comments (if any):

5. Overall, is the information well-presented, logical, and understandable?

Strongly disagree ↔ Strongly agree*

1 2 3 4 5

Additional Comments (if any):

As commented on above, I think the internal referencing is especially useful.

6. Please comment on the strengths and limitations of the overall product and its potential usefulness to managers and others.

Strongly disagree ↔ Strongly agree*

1 2 3 4 5

Product is useful to managers & others?

As a person involved in vegetation research, rather than animal research, I found this report very clear and readable. Thus, I think it should be accessible to non-specialists.

Comments on strengths and limitations:

As mentioned above, this is a well-organized and well-written review of the snail kite and apple snail monitoring efforts since 1969. I have commented on how I think that considering the distribution of these organisms in the predrainage Everglades might provide new insights into their current biology. I have additional comments that emerged as I considered the information in the report—these are not directly strengths or limitations of the report but are things that I think are worth considering in the larger research and monitoring context. I therefore will discuss them in the next section.

7. Other comments?

Scale disjunctions: The report provides a good description and is sensitive to the temporal disjunctions in the life cycles of the kite and snail. I do not think that the spatial disjunctions are as clearly considered, although they are mentioned in places. There are two spatial issues. One is from the perspective of individuals. Individual snail kites move over a very large area, whereas individual apple snails move over a much more limited range. With respect to vegetation, therefore, snails could be expected to be much more sensitive to vegetation on the

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scale at which vegetation varies in the Everglades, i.e., plant community distribution and abundance is more important to snails than to kites.

The other spatial issue is from a population and landscape perspective. Kites have limited geographic distributions. I do not have a clear feeling from the report, however, on the landscape-scale distribution of snails. The report indicates that they are not present in deeper water or shallower water, but are they everywhere in between? If you were modeling snail distribution would it be random (or uniform) throughout potentially available hydrologic habitat? How does this distribution relate to vegetation? The report describes reduced snail densities in water lily slough, but on what scale? Are they present in more open parts of such sloughs, and at what densities? What is their relation to floating periphyton mats (the use of *Utricularia*/periphyton as a food source in diet experiments suggests some type of use, but what species of *Utricularia* was this, and what type of periphyton mat?).

In the report, there was no consideration of snail population responses to fire and/or lightning strikes. Dry season fires, which can cover large or small extents, presumably lead to high snail mortality, which should translate to low snail densities in the following year, at least, and depending on snail dispersal and re-colonization, perhaps to low snail density in subsequent years. Wet season (water surface fires), in contrast, might lead to increased snail growth rates through fertilization effects on vegetation. Lightning strikes presumably would lead to snail death in some small area throughout the year. These effects should influence heterogeneity in the landscape-scale snail distribution discussed in the previous paragraph. Thus, some understanding of these effects, and of snail dispersal and re-colonization, should help to understand patterns of snail distribution.

Similarly, what are the cold tolerances for apple snails at different life stages? They become inactive below 13 ^{o}C (p. 110, 3312), but do freezes or extended cold-snaps cause massive die-offs, depending on water depth?

Snail foraging vs. egg-laying habitats: Snails seem to be able to survive and thrive on SAV, which cannot support air-breathing (p. 116, l. 3490-3494), and such vegetation could not support egg-laying. Snails have to have vegetation or periphyton of some sort to survive and grow, but they do not have to have vegetation to lay eggs, as these can be attached to non-plant substrates. Thus, analysis of habitat requirements for these two activities in relation to vegetation can be uncoupled from each other and, although the requirements for both activities can be met by the same type of vegetation in certain cases, they do not have to be. Understanding snail dietary requirements or limitations seems more critical to understanding snail distributions than understanding egg-laying requirements. How are the dense populations reported on SAVs maintained?

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External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
1	Executive Summary, p. iii, l. 6-8	The sentence beginning "Long-term…" is unclear; I think you mean "wetlands require hydrologic variation…, rather than "management requires". Reword?	Jennifer Richards	We edited the sentence to make it more clear.
2	1,3,73-75	It would be nice to reference Fig. 3-5 here, or maybe move it up (i.e., nice to have a distribution map early on)	Jennifer Richards	Agree; we have added a new figure here, 1-1.
3	1,3,77	The references to wetland loss should also reference McVoy et al. 2011; incorporation of this description of Everglades landscape here and elsewhere would be useful.	Jennifer Richards	We reviewed McVoy et al. (2011) and agree it is an excellent reference on wetland loss in the Everglades. We have added it as a reference in several places (see other JR comments on McVoy et al.); however, we did not add it to this sentence because this text (and references) was focusing on habitat loss in relation to kites, and we present a few of the references that address wetland habitat loss for kites specifically.
4	1,4,106	"this report" rather than "the report"	Jennifer Richards	Done.
5	1,4,111	replace "for the plan includes that focusing on" with "for the plan focuses on…."	Jennifer Richards	Done.
6	1,6,178	reference to Figure 2-1: it would be nice to locate gage 3A-65 on this map, to provide context for Figure 2-2.	Jennifer Richards	Locations of 3-65 and other gages are now on Figure 2-1.
7	2,10,262	most recent **statewide** estimate?	Jennifer Richards	Done. Removed "statewide" from the previous sentence.
8	2,10-11,273-300	This is a very useful and important discussion	Jennifer Richards	Great. No action needed.
9	2,13,357-359	field telemetry studies **of snails?**	Jennifer Richards	Done. Clarified.
10	2,13,362	remove "," after Florida, replace ";" with "," after "2007)"	Jennifer Richards	Made the first edit; for the second, there was no semicolon to change.
11	2,14,399-403	discussion of edge effects and disjunction of sampling vs. egg counts is interesting--I don't remember discussion of it later	Jennifer Richards	We edited this section of the text to point out the reason for sampling a meter away; in part, this relates to the purpose of sampling at the time to focus on where snail kites forage. So given that objective, we don't see a lack of data on snail densities in the ecotone as a problem. There is also a recommendation in the report to sample from within sawgrass out to slough.

External Peer Review Comments: Phase 1

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
12	3,16,446-447	This would be another good place to consider and cite McVoy et al. 2011.	Jennifer Richards	See response under comment # 3 above. Also, we added a note to the text that refers to the last section of Chapter 3 for a discussion of habitat alteration; this section is where we added the McVoy et al. citation.
13	3,18,505-507	It's unclear why just one of the hind legs is considered to be shaped like a snail operculum.	Jennifer Richards	We edited the text and changed the orientation of the photos in Figure 3-2 to better illustrate the point.
14	3,19,525	"wax myrtle", not "was myrtle"	Jennifer Richards	Fixed
15	3,19,534	"low stem", not "low-stem"	Jennifer Richards	Edited.
16	3,19,534-537	some indication of what "low" and "high" density means would be good, if possible. The 30-40% open water in l. 548 is informative.	Jennifer Richards	The text in that paragraph had already stated that more information on the topic would be presented in Chapter 5. We edited that sentence, but believe that what we have is adequate; we are also trying to limit redundancy.
17	3,19,540-541	What is the effect of floating periphyton on foraging behavior?	Jennifer Richards	Sykes alluded to this question, but other than that there are no published data. We added a statement from the Sykes publication.
18	3,20,551	"Snails **can be** captured"	Jennifer Richards	Change made.
19	3,23,635-642	Since the issue of snail density would seem to influence foraging time, it seems worth mentioning here (I'm assuming these studies have no data on snail densities)	Jennifer Richards	Correct- these studies do not have associated snail density data. We added a sentence referring to Chapter 7, which provides information on foraging when snail densities are known.
20	3,26,754	delete "and"	Jennifer Richards	Done.
21	3,27,769	"jamaicense", not "jamaicensis"; also, add "," after "(*Cladium jamaicense*),"	Jennifer Richards	Done.
22	3,27,769-770	"(*Typha* **spp**.)"--to make comparable to "(*Scirpus* spp.)"; presumably the *Typha* could be either *T. domingensis* or *T. latifolia* .	Jennifer Richards	Had gone with what the source indicated, but made the recommended change.
23	3,27,781-782	Did these authos provide data on relative abundance of willow vs. melaleuca in WCA 2B?	Jennifer Richards	No, the authors did not provide such data; we stated this in the discussion.
24	3,28,794-795	These bulrush species have new names: *Scirpus californicus* = *Schoenoplectus californicus* ; *Scirpus validus* = *Schoenoplectus tabernaemontani*	Jennifer Richards	At each of the ~11 places the species were mentioned we added the new names.

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Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
25	3,28,815	unclear what the" water depth averages" are averages of--the whole breeding system, something else?	Jennifer Richards	Clarified the sentence.
26	3,38,816	"similar depths" to what--the averages, some of the other numbers given previously?	Jennifer Richards	Edited to clarify (was page 28 not 38).
27	3,30,869	"Adult snail kites usually feed **their** young extracted snails"	Jennifer Richards	Changed.
28	3,32,915	"those years **(Sykes** 1984)"	Jennifer Richards	Fixed.
29	3,32,915-916	The sentence "On WCA3A during...." is unclear; WCA3A is west of the L-67 canals, so I'm not sure what is being said here.	Jennifer Richards	Clarified the sentence.
30	3,35,1030	"presumably did not"--this is an odd statement; does it mean that on revisits to nests, some chicks were there but others weren't?	Jennifer Richards	Yes, that is what occurred and "presumed" is the word they used. However, we have clarified this sentence.
31	3,39,1131	another place to bring in McVoy et al. 2011.	Jennifer Richards	McVoy et al. (2011) was added as a reference to this section.
32	3,39,1146	"see Sklar et al. (2002) **and McVoy et al. 2011**)	Jennifer Richards	McVoy et al. (2011) was added as a reference to this section.
33	4,44,1290	"**In** a spring system"	Jennifer Richards	Changed.
34	4,44,1292	"Eich**h**ornia"	Jennifer Richards	Fixed.
35	4,44,1290-1293	This sentence is somewhat confusing. *Vallisneria* is an SAV, while *Eichhornia* and *Pistia* are free-floating aquatics that float at the surface. So the snails are more common in the SAV, using the trees to respire and lay eggs?	Jennifer Richards	Bryan (1990) did not elaborate on this, which is the paper we cited. However, Darby (pers.obs) noted that *Vallisneria* often reached the water surface in his field studies on lakes and rivers; this observation has been added to the text.
36	4,44,1297	"**In** a central Florida lake...."	Jennifer Richards	Changed.
37	4,45,1299	When *Nuphar* grows densely, the leaves become emergent, with the petioles raising the laminae above the water surface; it seems like this situation could support apple snails.	Jennifer Richards	Good point. We've added the point in the appropriate location in the text. Note that at the time the *Nuphar* was sampled it grew over unconsolidated organic "muck" with no SAV (which may explain the zero snails). Later, in that same site Darby found snails and eggs deposited on *Nuphar* in a consolidated substrate that also had SAV (Darby et al. 2004).
38	4,46,1336	"*Na**j**as marina* "	Jennifer Richards	Edited.

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Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
39	4,46,1347	delete "," after "development)"	Jennifer Richards	Comma deleted.
40	4,46,1357-1359	It would be nice to give some idea of how far the snails move--i.e., what the "greatest" distance is (cm, m, km?).	Jennifer Richards	We have added a few sentences about distances traveled.
41	4,47,1367	"structure**s**"	Jennifer Richards	Done.
42	4,47,1382	In all of the species mentioned, the snails would be laying on leaves, not stems; so "broad leaves > 6 mm. *Eleocharis* , however, is a stem. In the Turner (1996) paper, he does call them all stems, and on of his pictures is of eggs on an inflorescence stald (=stem), but his counts of "stem" density are much too high to be stems, so it must be that he was counting leaves….	Jennifer Richards	We discussed this comment with the reviewer. We modified the text to incorporate the comment.
43	4,47,1387	How long were the snails kept in enclosures? What was the period over which they laid eggs?	Jennifer Richards	Done. Information has been added to the paragraph to address the questions.
44	4,48,1397-1401	Are there no predators on these eggs?	Jennifer Richards	In this paragraph we added a sentence that refers to a subsequent page (page "54") that discusses predation on eggs. On that page, we added some additional discussion of the Dreon et al. 2010 publication (about the eggs' bitter taste and lack of predators).
45	4,48,1418	Fig. 4-4 does not seem to me like a conceptual model of a life history; Fig. 6-2 seems more like such a conceptual model. Fig. 4-4 seems more like a model of the age structure of the population.	Jennifer Richards	We deleted 'life history' and rephrased this sentence of the text to more accurately reflect what is shown in Figure 4.4. Figure 6-2 is more narrowly focused on hatchling growth and maturation to a redproducing adult; we do not agree that it represents the life history, as no indication of survival or seasonal peaks in eggs, juveniles, etc. are shown. We have not changed the Figure 6-2 title/description.
46	4,53,1569	"exotic**s**"	Jennifer Richards	Edited.
47	4,55,1634	"as well as **to** aid"	Jennifer Richards	Edited.
48	5,56,1661,1663,1669, 1670, 1675	use "can" instead of "may": can refers to ability to, while may refers to permission.	Jennifer Richards	Edited.
49	5,56,1668	insert "," after "1995)"	Jennifer Richards	Done.

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Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
50	5,59,1771-1775	I think an explanation of "censoring" would help better understand this paragraph	Jennifer Richards	Done. Added a brief explanation and clarifying phrases.
51	5,63,1883-1884	This discussion would be more useful if some indication of which direction in change in water level was associated with dispersal or survival (i.e., not just change, but increased or decreased depth/level/index). What does a higher water level index mean?	Jennifer Richards	We had refered the reader to Appendix C to get details on the water level index. In our current revision, we clarified that this index is the same as a drought score value, DSV, described in Appendix C. As far as direction of change, this was clarified in the revised text. Note that dispersal (=natal departure) and water levels were both explanatory variables for the survival model, so they did not discuss the effect of water on dispersal.
52	5,64,1911-1917	This paragraph reports 2002-2005 populations of 1,100-1,500, but than says that the MCs and FCs were always below 650 birds from the year 2000 on. This seems contradictory--maybe say "Unadjusted MCs and FCs"?	Jennifer Richards	The text was modified to more clearly distinguish between unadjusted / raw counts and p-hat adjusted mark recapture estimates.
53	5,69,2068-2077	This paragraph seems to present new technology but doesn't provide any results; is the data consistent or inconsistent with previous results?	Jennifer Richards	Done. Added a sentence to the paragraph referring to results presented under "Monthly and Seasonal Movements."
54	5,71,2113-2114	The comment about kite movements not being influenced by dry conditions is confusing--is this because there were not dry conditions during this time, as noted previously? Is that what is meant here? I.e., is it "did not experience" rather than "were not influenced by"?	Jennifer Richards	Agree. We edited the text in parentheses to clarify.
55	5,71,2122	what is the meaning of the "/" between "and" and "more"?	Jennifer Richards	Edited the sentence; deleted the "/".
56	5,73,2181	So here is the data from Meyer et al. (2009); this is really interesting data, especially about the small wetlands. Maybe just mention that it is coming, back on p. 71.	Jennifer Richards	Done. See response to # 53 above.
57	5,77,2305	"were based **on** the annual"	Jennifer Richards	Fixed.
58	5,82,2472	move "," to after 2001	Jennifer Richards	Done.
59	5,82,2473	Either have a figure that locates this gauge, or give some indication of where it is (e.g., "south central WCA3A").	Jennifer Richards	Added reference to Figure 2-1, where we added the locations of the three gages.
60	5,89,2690	"no kite nests" (remove "s")	Jennifer Richards	Edited.
61	5,94,2832	*Scirpus validus = Schoenoplectus tabernaemontani*	Jennifer Richards	Done.

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Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
62	5,97,2932	Both torpedo grass and alligator weed are exotics; also, they do not grow very tall, although they can be very dense; you say later that the snails tend to avoid these two plants, rather laying eggs on pickerelweed and bulrush.	Jennifer Richards	We agree with the comments about the structure of the plants, and this is consistent with snails avoiding them *for egg laying* . Exotic or not, these were the dominant plants at the time of Darby's work. There is no inconsistency here. Snails move, so we find snails in habitats where they do not lay eggs; later in the report when we talk about avoiding alligator weed and torpedo grass, we mean as far as laying eggs.
63	5,97,2944	*Scirpus validus = Schoenoplectus tabernaemontani*	Jennifer Richards	Done.
64	6,101,3044	"two possibilities**. The** first"	Jennifer Richards	Done.
65	6,102,3067	"lower tolerance to survive" seems an awkward phrase. Lower survival rate?	Jennifer Richards	Edited this sentence to address the comment.
66	6,103,3112-3114	is there any information on competition among snail consumers? A related question is what proportion of snails consumed are consumed by snail kites?	Jennifer Richards	There are no data available on either of these topics. The second question is included in one of the recommendations for snail research in Chapter 11. The proportion of snails consumed by kites would vary due to various conditions (e.g., temperature, habitat structure, water depths, and the relative prevalence of a suite of aquatic and avian snail predators).
67	6,106,3175 and Fig. 6.2	Figure 6.2 needs some indication of scale, such as at least a scale bar for the shell sequence.	Jennifer Richards	A scale bar was added for the shell sequence.
68	6,109,3264	"(>1.0**/m^2** in "	Jennifer Richards	Done.
69	6,109,3274	"mm) **was** higher"	Jennifer Richards	Edited.
70	6,109,3275	delete the "("	Jennifer Richards	Done.
71	6,110,3309	replace "that is constrained" with "constrained"	Jennifer Richards	Done.
72	6,111,3325	is the data on water depth supression of egg production independent of submergence of vegetation on which to lay eggs? i.e., is it a direct effect of water depth?	Jennifer Richards	Yes, it's independent of submergence -- depths discussed were NOT above sawgrass on the ecotone. Darby counts eggs on emerged vegetation along ecotone. The comment was addressed by adding a sentence stating that emergent vegetation was not below the water surface. Also added a similar statement 6 paragraphs above this one.

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Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
73	6,111,3344	The *Utricularia* -periphyton complex was presumably *U. pupurea* , which froms the backbone of the most common type of floating periphyton mat in the Everglades; this mat is common in both sloughs and wet prairie and can harbor an in-fauna. Is it known whether young snails inhabit these mats? The following reference is a possible source of information: Shawn E. Liston and Joel C. Trexler (2005) Spatiotemporal patterns in community structure of macroinvertebrates inhabiting calcareous periphyton mats. Journal of the North American Benthological Society: December 2005, Vol. 24, No. 4, pp. 832-844.	Jennifer Richards	Sharfstein and Steinman did not report the species; this was made more clear in the text. We also added sentences related to Liston and Trexler (2005), and from Darby et al. (2009) showing no significant effect of *Utricularia* presence on snail densities.
74	6,112,3367-3368	If by "sawgrass detritus" these authors meant biomass equivalent to standing dead or shed sawgrass leaves, this material is very nutrient depleted; it would be interesting to compare periphyton and living sawgrass biomass, assuming the snails can eat living sawgrass. The following point about periphyton on sawgrass is also well-made.	Jennifer Richards	The publication does not describe the detritus obtained from the sawgrass community, so we could not provide additional detail on that. However, we edited the text to note that sawgrass-epiphyton may be important to hatchling snails. There is a recommendation in Chapter 11 to address these types of questions (i.e., related to food preferences).
75	6,112,3378-3379	We do not know how stable floating periphyton mats are through time, so I do not think you can characterize them as being present or absent from water lily sloughs. Sometimes they are present, sometimes not.	Jennifer Richards	The point is understood. However, the text is presenting what Karunaratne et al. reported at their sites when they sampled. We do not think any changes are needed.

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Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
76	6,113,3401	again, these plants are presenting leaves, not stems, for oviposition.	Jennifer Richards	The text was modified to address the comment.
77	6,114,3415-3416	re egg densities: need to say whether are eggs/m2 or clutches/m2	Jennifer Richards	Done- clarified based on what the publication reports (added one word to indicate egg cluster densities).
78	6,114,3422-3424	I'm assuming that these are actually petioles of leaves, not stems.	Jennifer Richards	The text was modified to address the comment.
79	6,114,3430	these plants are "broad-leaved" plants, but the structure of interest to the snail is the rounded petiole of the leaves.	Jennifer Richards	The text was modified to address the comment.
80	6,114,3435	*Scirpus* = *Schoenoplectus*	Jennifer Richards	OK.
81	6,115,3467	"find both of these needs **met**"	Jennifer Richards	Done. Edited the sentence as suggested.
82	6,116,3472-3473	"submerged plant and periphyton growth, which appear to be important for apple snails"--this point has not come across clearly; growth when fed was reported, but the data from Chap. 4, pp. 45-46, do not really make clear what the snails eat *in vivo,* so it's not clear what would be good vegetation for foraging snails.	Jennifer Richards	We deleted this sentence.
83	6,116,3490-3492	"**in** a spring system"; this paragraph seems to be saying that snails like SAV, but such vegetation does not provide them access to air. Such plants may be more amendable to snails in springs, which have flowing water and so may provide better aeration for gill breathing, as opposed to the Everglades.	Jennifer Richards	The change to "in" was made. We can only report what Bryan (or others) reported, and unfortunately there were few details. Saying there were more snails in tape-grass vs. water lettuce does not mean emergent species were not present. Also, Darby (pers. obs.) noted that SAV frequently reach the surface in springs, lakes and in Everglades marshes, depending on water level, so snails could reach the surface to breathe. The more important point in the sentence was that few snails were found in areas blanketed by plants like water lettuce, and SAV in general does support *Pomacea* snails. Also note that snails move frequently, so they don't have to have emergent plants in every microhabitat in which they can be found (e.g., they can move to a location where emergent plants occur).
84	7,128,3834	do you mean "2006-2007), while Darby et al."	Jennifer Richards	This sentence was revised to be more clear.

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Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
85	8,131,3893	replace "was developed to project" with "projected"	Jennifer Richards	Done.
86	8,132,3903	unclear what is meant by "status"	Jennifer Richards	Clarified based on the publication.
87	8,135,3991-3994; 4007-4008	the modeling of snail populations would be greatly enhanced by estimates of suitable vegetation cover at appropriate scales. This is now becoming possible with some remotely sensed data (see Gann et al. 2012, referenced in General Comments) and should greatly improve these models.	Jennifer Richards	The modeling team has considered using this type of vegetation data in the model. For the report, we have included mention of it in Chapter 8 (for future work, where we had already stated that vegetation will be accounted for in the model in the future), as well as in the recommendation in Chapter 11 dealing with the snail model. At this point, the model has not been developed enough to use this kind of info. Additionally, preliminary analysis for SAV shows no clear preference of type by snails. These data and hydrology are currently being analyzed in a Bayesian framework (publication yet to be completed).
88	8,137,4056	remove "d" from "estimated"	Jennifer Richards	Done.
89	9,140,4134	delete all 3 commas	Jennifer Richards	Done.
90	9,140,4134	delete second comma	Jennifer Richards	See above.
91	9,141,4153	begin sentence with "Assumptions that apple snails are unable..."	Jennifer Richards	Edited.
92	9,141,4154	the "without considering actual depths" is ambiguous; do you mean "without considering upper limits of depth"?	Jennifer Richards	Clarified.
93	9,141,4170	be better to say "federally designated, ecologically critical wetlands."	Jennifer Richards	We uderstand the comment, but it is not correct. Many of the important wetlands used by kites are not federally designated critical habitat. However, we will edit the sentence to just say "ecologically critical wetlands" to be more clear.
94	9,141,4173-4174	move "WCA3A," to after "success in"	Jennifer Richards	Done.

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Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
95	9,141,4174-4176	This point didn't really come out in the review (i.e., exotic snails and exotic plants), so it is surprising to see it here.	Jennifer Richards	Kites nesting more on LTOHO, where the exotic snails are increasing, is a relatively recent development. We have added a new section in Chapter 7 to provide some additional discussion of the topic.
96	9,142,4189	the connection between low snail densities making poor habitat AND this resulting in habitat fragmentation is not clear; this needs to be reworded or further developed	Jennifer Richards	Manuscripts and reports on kites do not make this connection. They tend to talk about 'habitat degradation' (see Chapter 5), but that term suggests changes in plant communities. Several reports/publications by Darby et al. report low snail densities, with some publications indicating what 'low' may mean in terms of snail densities. We clarified the point we were making in Chapter 9; it is a product of our own synthesis of the pieces of information that were presented in earlier chapters.
97	9,142,4206	"stem**/leaf** densities"	Jennifer Richards	Text was modified.
98	9,143,4213	"than **those** documented"	Jennifer Richards	Edited.
99	9,143,4215	"depths below **those that support** kites"	Jennifer Richards	Edited.
100	9,143,4220-4222	There is a disjuntion between the scale at which kites move/operate and snails move/operate that hasn't been considered. This translates into a disjuntion in how water operates in this system, i.e., a dry-down for snail kites may leave hydrated habitat for snails because differences in microtopgraphy in the landscape (dry on ridges, wet in slough or wet prairies). Thus, the EDEN estimates of water depth may work at the kite level but not be good predictors at the snail level.	Jennifer Richards	We do not agree that we had not considered this, but we have made it more clear in this revision. We added a sentence in the next paragraph to make the point about responding to hydrology at different scales. We also added the point in the appropriate recommendations (e.g., see recommendation D-6 in Chapter 10). We agree that the EDEN data better represent what kites deal with compared to what snails deal with.
101	9,143,4229-4230	I think there is also a need to consider at least 3 spatial scales: the scales at which kites move, the scales at which snails move, and the scale of variability of suitable snail habitat, which requires both feeding and structural vegetation. Additionally, there has been no mention of fire effects, which can be large in the Everglades portion of the ecosystem.	Jennifer Richards	We agree that the document has not addressed fire; there is no information available on the topic with regards to snails and snail kites. We have added a recommendation to monitor/research fire effects in Chapter 11. Regarding the spatial scales comment, see response immediately above.

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Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
102	9,145,4283-4286	We also have vegetion maps and are developing the remote-sensing capabilities to create additional maps at resolutions appropriate to answering questions about habitat distribution for these species. See General Comments.	Jennifer Richards	The FL apple snail model is being developed with JEM, and JEM has considered this. We have added specific reference to these advances in the research recommendation in Chapter 11 dealing with snail kite and apple snail models.
103	10,147,4345	suggest deleting "it"--unclear what it refers to	Jennifer Richards	OK, Done.
104	10,147,4346	results of what? Results of our changes? Results of on-going research and monitoring?	Jennifer Richards	Will clarify; by "results" we mean how animals and plants respond to hydrologic/habitat management changes.
105	10,147,4351	do you mean "resource" instead of "source"?	Jennifer Richards	Yes, fixed.
106	10,148,4354	delete comma	Jennifer Richards	Done.
107	10,148,4364-4366	This could be monitored at a much finer scale than the EDEN water depth grid using remote sensing (Landsat imagery has a 30x30m pixel; finer-scale imagery is also available--see Gann and Richards 2009 and Gann et al. 2012.)	Jennifer Richards	No apple snail or snail kite study has incorporated this approach. We referred to these finer scale approaches in recommendation 11-5 of Chapter 11.
108	10,148,4374	delete comma; change "and **for** ways to"	Jennifer Richards	Edited sentence.
109	10,150,4418	replace "recommended" with "had"	Jennifer Richards	Done.
110	10,150,4418-4420	this sentence is awkward; maybe delete "for the Everglades"	Jennifer Richards	Edited sentence.
111	10,150,4427	"Both **kites and snails** are"	Jennifer Richards	Done.
112	10,150,4428	relace comma with dash; remove comma in next line	Jennifer Richards	Done.
113	10,152,4479-4480	I am unclear on what this sentence means. What would doing this look like?	Jennifer Richards	We deleted this sentence as well as those relating specifically to WCA3A because they detracted from the intent of the recommendation.

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Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
114	10,157,4660	I wondered if this statement refers to WCA3A, instead of WCA2B; it's not clear to me why the comparison would be made to this wetland that is more distant from BICY.	Jennifer Richards	The original statement was correct, but we have clarified it. In some of the movement analyses discussed in Chapter 5, BICY is in the same region as WCA3A and WCA2B, and we are making the case that analyses should be made on a wetland unit basis, or at least a wetland unit basis in addition to regional analyses (when regions may contain wetland units with very different conditions). For example, 2B is often flooded while BICY is dry.
115	10,158,4673	delete the second "to" ("to determine to")`	Jennifer Richards	Done.
	10,159,4692	For egg clusters, this type of monitoring program could easily be part of a "citizen scientist" type of effort.	Jennifer Richards	To minimize redundancy, this and the third recommendation were combined. We noted that citizens could potentially be involved in egg cluster monitoring. However, it should be noted that sampling egg clusters is not necessarily easy logistically (e.g., gaining access to the area to sample). Also, there would need to be a standardized protocol, training demonstration in the field, and a QA/QC assessment of field methods and data collection/entry.
116	10,159,4711	LG2 is not defined anywhere	Jennifer Richards	Full name of company was added.
117	10,159,4715	"scale **relevant** to"	Jennifer Richards	Done.
118	10,159,4714-4727	This recommendation gets at the different spatial scales of these two organisms and is very important. One approach would be to map a circle with a foraging radius out from kite nests or roosts, identifying snail habitat within that circle, then sample snail densities within snail habitat.	Jennifer Richards	No change to text needed. Regarding the suggestion, note that kites do not always forage in immediate vicintiy of nests or roosts, so the circle-radius idea cannot be consistently applied. Delineating foraging habitats and associated snail densities is currently underway with Darby (UWF) and Cattau (UF).
119	10,161,4767-4769	The meaning of "target" in this sentence is unclear. Target for what? Target how?	Jennifer Richards	The language has been clarified.
120	10,161,4775	"maidencane **[*Panicum hemitomon*]**"	Jennifer Richards	The scientific name was stated previously, but we have added it again here.

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Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
121a	10,161,4781	I think *R. tracyi* is probably too narrow-stemmed and leaved to support snails. Maybe *R. inundata* could, but this is not as common as *R. tracyi* and probably has deeper-water hydrology.	Jennifer Richards	We believe that the text does not need to be changed because we did not specifiy species. However, in terms of egg-laying we see your point. PCD has seen snails use *Rynchospora inundata* for egg-laying. Rob Bennetts has observed kites foraging in *R. tracyi* -dominated areas. Also, even if snails use other plants for egg-laying, e.g., along the ecotone, they may still use *Rynchospora* for respiration (where they climb the underwater portions of the vegetation to reach the air).
121b	10,162,4784	*Scirpus* = *Schoenoplectus*	Jennifer Richards	OK, edited.
122	10,162,4786	the reference to wild celery is very unclear. If *Apium graveolens* is meant, this is not a SAV. If this is an alternate name for *Vallisneria* , I'm not sure where it comes from.	Jennifer Richards	Wild celery is another common name for *Vallisneria americana;* perhaps it is used more often on the lakes (e.g., see J. Aquatic Plant Management 42:49-53). However, we will just use the common name "tape-grass" in the report.
123	10,162,4786-4787	The comment about the frequency of *Pontederia* to *Sagittaria* must refer to lakes, so this needs to be made clear. In the Everglades region, *Sagittaria* is more common that *Pontederia* --this was seen quantitatively in both the 1999 and 2005 REMAP plant census data across WCA1, 2, 3, and ENP.	Jennifer Richards	The original statement is correct and does apply to the lakes. We made this more clear by separating the background into 2 paragraphs and adding the phrase "in central Florida lakes" to the subject sentence.
124	10,162,4811	"**Snail kites** dropping lare exotic snails **have** been"	Jennifer Richards	Done.
125	10,163,4844	delete "studies" (it appears again on next page)	Jennifer Richards	Done.
126	10,165,4883	This recommendation seems the same as or part of the recommendation at the beginning of this section (10,163,4823	Jennifer Richards	The recommendation here was intended to be web-based, although that was not clear. We clarified the recommendation and combined it with the earlier recommendation noted.
127	1,170,5010	replace "have" with "has"	Jennifer Richards	Done.
128	11,170,5019	EDEN also has water depths for Everglades National Park and Big Cypress National Preserve.	Jennifer Richards	OK, added.

External Peer Review Comments: Phase 1

Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
129	11,172,5089	I agree that this is an important and relatively unknown area, based on the review presented here. The studies presented gave a confusing picture of snail food preferences, given snail habitat.	Jennifer Richards	No change needed.
130	11,173,5103	I agree that this is another very important and understudied area. After reading the report, I am left with many questions about where apple snails would be expected to be found.	Jennifer Richards	We believe that there is a substantial amount of information in the report on where apple snails are found. There are data that show clear differences in snail densities between different juxtaposed habitat types- some published in journals and some in reports; studies were designed to test these comparisons (see chapters 4 and 6). These publications and reports certainly do not include all of the habitats in the kite's range, but we can and have found snails in many habitats. There are snails in habitats that are not used by kites (e.g., in moderately dense/dense cattail [Valentine-Darby et al. 2008). To make it clear that some information on snail densities in other habitats does exist, we added discussion in Chapter 4, Range, Distribution, and General Habitat Needs.
131	11,173,5117	Again, this seems like important and useful data; note, also, data by J. Trexler's lab (FIU) in the Swales report (Bramburger et al., 2011, given in General Comments)	Jennifer Richards	Addressed. In the recommendation added that any existing apple snail data for ENP should be reviewed. Note that the data presented in Bramburger et al. (2012) is only for snail egg clusters, not snail densities.
	C-1,6029	insert comma after "So"; delete comma after "1996"	Jennifer Richards	We added some additional text in Range, Distribution, & Habitat Needs to make it clear that other data on snails are available.
132	C-3,6102-6103	"drought" is repeated twice in the list.	Jennifer Richards	Edited.
133	C-4,6114	the ")" needs to be moved to after "depths"; either that, or something is missing from this sentence.	Jennifer Richards	Edited.
134	D-1,6132	by "figures", do you mean "data"?	Jennifer Richards	Yes, edited.
135	D-2,6149	rearrange: "the woody substrate most-used by kites"	Jennifer Richards	Edited.

External Peer Review Comments: Phase 1

Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
136	D-2,6157	Willows don't tiller, but they are well-known for coppicing (production of new shoots from old stem tissue) (Saska and Kuzovkin, 2010, Ann Appl Biol 156: 431–437)	Jennifer Richards	This sentence was edited to incorporate the comment.
137	D-3,6180-6187	a review of hydroparameters for willow can also be derived from Gann and Richards, 2009, which also includes a literature review for hydrologic parameters for woody communities in the Everglades region.	Jennifer Richards	We reviewed Gann and Richards (2009) and added a few sentences to the report. Because the information in the reference was not specifically for willow, we provided more of an overview and reference to Gann and Richards.
138	D-4,6211	The *Typha* species in Florida are *Typha domingensis* and *T. latifolia* .	Jennifer Richards	We had not included the two species names because not all of the references mentioned them; however, we have added them to the text.
139	D-4,6214-6217	The expansion of cattail is a concern throughout the entire Everglades region.	Jennifer Richards	We edited the text to be more inclusive.
140	D-4,6220-6221	These two species have somewhat different hydrologic tolerances, but there is a tremendous amount of overlap (Gann and Richards, 2009). The more important difference is probably their response to nutrients, especially P, e.g., Childers, D. L., R. F. Doren, R. Jones, G. B. Noe, M. Rugge, and L. J. Scinto. 2003. Decadal change in vegetation and soil phosphorus pattern across the Everglades landscape. Journal of Environmental Quality 32:344-362. and Doren, R. F., T. V. Armentano, L. D. Whiteaker, and R. D. Jones. 1997. Marsh vegetation patterns and soil phosphorus gradients in the Everglades ecosystem. Aquatic Botany 56:145-163.	Jennifer Richards	No corrections were required, but we added the points, including citation of the 3 papers/reports mentioned, to the text. The point about cattail expansion and its relationship to nutrients was not the main point of this section- it was on the hydrologic conditions under which cattail grows. This plant is different from the others mentioned in this appendix because although the kite uses it for nesting, cattail is an undesirable species in many situations.
141	D-4,6224 and 6227	add an "s" to "nutrient"	Jennifer Richards	Change made.
142	D-4,6234-6235	The absence of cattail in these habitats is much more probably a result of low nutrients than inhibition by other species. When nutrients are added to these habitats, and conditions allow for seedling establishment, cattails invade.	Jennifer Richards	We were stating what others had reported (i.e., Lodge book); however, we deleted the sentence.
143	D-4,6231-6239	see also Gann and Richards, 2009	Jennifer Richards	Revised to include information from Gann and Richards (2009).
144	D-4,6246-6247	The question, of course, for sawgrass is how deep and how prolonged in order to induce mortality; sawgrass can grow in a wide range of water depths (see estimates for WCA 2A in Gann and Richards, 2009).	Jennifer Richards	We agree. We do not see that the text is inconsistent with the comment, so we did not change it, but we added a reference to Gann and Richards 2009.

External Peer Review Comments: Phase 1

Comment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
145	D-4,6252-6256	The major result of the Hendon et al. 1991 study was that if sawgrass culms are submerged (flooded) after burning, the culm apex dies. I am not sure that this comes through clearly from this paragraph. So the time of burning doesn't matter, although May and June are the likely times for this scenario to occur.	Jennifer Richards	Clarified the sentences.
146	D-5,6263-6265	This relationship between sawgrass height+density and hydroperiod is probably an indirect effect of a relation between sawgrass height+density and peat vs. marl soil.	Jennifer Richards	The statement about this relationship came from Lodge (2010); we edited the sentence to address the comment and also added a reference to Gunderson (1994).
147	D-5,6266-6276	see also Gann and Richards, 2009	Jennifer Richards	We reviewed the report's review of sawgrass studies and added some material.
148	D-6,6279	*Scirpus* = *Schoenoplectus*	Jennifer Richards	Addressed.
149	D-6,6280	*S. validus* = *Schoenoplectus tabernaemontani*	Jennifer Richards	Addressed.
150	D-7,6329	"84-99% **days inundated**."	Jennifer Richards	Addressed.
151	D-8,6347	"period of record"?	Jennifer Richards	We believe text is fine as is because the periods where not necessarily the same for the different wetland units.
152	D-8,6349	delete comma after "this" and "1997a)"	Jennifer Richards	Done.
153	D-9,6392	replace "is" with "provides"	Jennifer Richards	Done.
154	Table 9-1.	Under Nesting Substrates: *Scirpus* = *Schoenoplectus*	Jennifer Richards	Done.
155	Table 9-2.	under Egg Laying Substrates: *Scirpus* = *Schoenoplectus ;* under Habitat/Vegetation: "Wild celery" is used as a common name for *Vallisneria,* which I don't think it is; in the next line, *Eichhornia* is missing one of the h's.	Jennifer Richards	Added clarifications. Will use "tape-grass" as the common name for *Vallisneria* , but "wild celery" is used in the literature (e.g., see J. Aquatic Plant Management 42:49-53).

PHASE 2 REVIEW

S. Wilcox and G. Ralph

External Review Comments: Phase 2

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
1	Throughout	There are many references throughout the document to see other chapters. It would make the document more user-friendly if the headers or footers included the chapter numbers.	Sue Wilcox, US Army Corps of Engineers	We fully agree and have added them in.
2	Chapter 2, page 12, line 325	Typo - "A successful nest is one in which at least one 'check' fledged." Should be 'chick'.	Sue Wilcox, US Army Corps of Engineers	Corrected.
3	Chapter 3, page 17-19, Diet	Were the reports of snail kite prey based on observations only? Were there any studies/reports on stomach contents?	Sue Wilcox, US Army Corps of Engineers	All information is based on observations.
4	Chapter 4, page 59, lines 1753-1755; Chapter 10, page 171-172, D-7; Chapter 10, page 174, E-4	Recommendation is made here for prevention and early detection to slow/prevent the spread of P. insularum; monitoring spread of exotic apple snails; and public education on reducing the spread of P. insularum. However, the FFWCC has changed management measures in Lake Toho to vastly reduce treatment of invasive Hydrilla so the exotic apple snail will be more abundant, for food for the snail kite. This management measure is counterproductive to attempts to prevent/control these two invasive species. Has FFWCC conducted studies and have data available that indicates the exotic apple snail is not a threat to native species and the Florida ecosystem? Can any FFWCC data be reviewed and an assessment included in this Pomacea Project report ?	Sue Wilcox, US Army Corps of Engineers	Such data are not available to our knowledge. At this time, snail kites are relying on exotic snails on several lakes, because native snail populations have declined in wetlands throughout the kite's range. We assume management support of exotic snail populations is temporary and not part of a long-term solution for kite recovery. In Chapter 11, we have included recommendations to study impacts of exotic snails.
5	Chapter 5, page 76-77, line 2281-2282	"...wetlands separated by < 5 km of matrix), and 3) isolated wetlands (a group separated by > 15 km of matrix)." What about between 5 and 15 km? Or is this a typo and item 3 should be "> 5 km"?	Sue Wilcox, US Army Corps of Engineers	There is no typo; this is what was in the publication.
6	Chapter 5, page 95, line 2839	Typo - extra period	Sue Wilcox, US Army Corps of Engineers	Corrected.
7	Chapter 5, page 95, line 2839	1984-1985 and 1988-1989 were excluded from the meta-analysis. Why were those years not included? Was data not available or were they excluded for a particular reason?	Sue Wilcox, US Army Corps of Engineers	According to the publication, there were no data for those years. This has been added to the report text.
8	Chapter 5, page 99, line 2979-2983	This paragraph discusses the number of kite nests known not to be impacted due to the implemented herbicide application buffer zones. Is there data reporting the success/failure of these specific nests?	Sue Wilcox, US Army Corps of Engineers	This was not the main point of this paragraph, but the authors did report fledglings per nest. Asentence has been added to report the information.
9	Chapter 6, page 118, line 3511	Typo - "...sawgrass were snails lay eggs in the..." 'Were' should be 'where'.	Sue Wilcox, US Army Corps of Engineers	Corrected.

External Review Comments: Phase 2

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
10	Chapter 7, page 129, line 3820-3821	Typo - "was to" is repeated twice.	Sue Wilcox, US Army Corps of Engineers	Corrected.
11	Apple snails - in general	Did any studies / reports include data on water velocities or wave run up (e.g. due to wind or boats)? Has any consideration been given to water velocities / wave run up in relation to apple snails, or just depth and hydroperiod?	Sue Wilcox, US Army Corps of Engineers	The questions asked are good ones, but have not been addressed for Pomacea paludosa. High FL apple snail densities have been observed in first magnitude springs (with high flow rates; see Corrao et al. 2006). Although there have been no studies of effects of flow rates on native snails in FL, there has been at least one study on flow rates and apple snails in Argentina (see Seuffert and Martin, 2012, Aquatic Ecology 46:129-142, "A lentic dweller in lotic habitats: the behavior of the invasive South American apple snail Pomacea canaliculata in flowing water).
12	Figures - in general	It would be beneficial to include legends down by the figure versus only in the text describing the figure.	Sue Wilcox, US Army Corps of Engineers	We examined the figures and decided that no changes were needed.
13	Chapter 1, Page 1, Line 20	Remove ")" after analyzed	Gina Ralph, US Army Corps of Engineers	Corrected.
14	Chapter 1, Page 3, Lines 87-90	Have you considered effects of water quality or pesticides on apple snails?	Gina Ralph, US Army Corps of Engineers	Yes, although not much work has been done in this area. Published information on the topic is presented in the last section of Chapter 6. Also, one of the reviewers of the report suggested that more work is needed on nutrient impacts on snails, periphyton, and habitat.
15	Chapter 2, Page 7	It would be helpful to provide a brief synopsis of census methodology and areas surveyed.	Gina Ralph, US Army Corps of Engineers	This information is provided a few pages later in the chapter, although it focuses more on current protocols. We have addressed some of the problems with the annual kite count that was conducted until 1994 (described by Bennetts et al. 1999a and discussed in the report). Since different researchers monitored kites in different years prior to 1994, and the areas and other factors varied, we did not address the particulars from each year/researcher in the report.
16	Chapter 2, Footnote 2 and elsewhere	It would also be helpful state stage and then to translate stage into depth to aid reader in understanding conditions during dry down events.	Gina Ralph, US Army Corps of Engineers	The EDEN data that hindcasts back to 1980 just recently came out, and it is beyond the scope of this project to provide details on depths (and no estimates exist prior to 1980). In this footnote, we do make the point that nearly all 3A is dry at stages <7.5 feet.

External Review Comments: Phase 2

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
17	Chapter 2, Footnote 2 and elsewhere	It would also be helpful to use standard gauge name in case reader would like to use EDEN or DBHYDRO to perform further analyses. The notation of gauge 3-65 may be confusing to some readers, it should be noted as either "Site 65", or by the gauge name of "3A-28" for proper identification. This same statement also applies for 3-63 (Site 63, or 3A-3) and 3-64 (Site 64 or 3A-4).	Gina Ralph, US Army Corps of Engineers	We agree with the need to minimize confusion. After checking in DBHYDRO, which is where we obtained the data used in this discussion, we edited the text, footnotes, and figures where the names occur. We provided both station and site names as they occur in DBHYDRO. For example, "3-65" is the "station" name in DBHYDRO, and the "3A-28" is the "site" name; data queries are done using either of these station or site names, so we have used these too.
18	Chapter 2, Page 8, Line 208 & Line 215	Rogers (1983) should be Rodgers (1983)	Gina Ralph, US Army Corps of Engineers	Corrected.
19	Chapter 2, Page 8, Line 213	How are you defining "dry", "wet" or "average" year?	Gina Ralph, US Army Corps of Engineers	The approach we have taken in presenting this information is to refer the reader to the footnote (at the end of that sentence) and Figure 2-2 so the reader can interpret this for themselves.
20	Chapter 2, Footnotes 3,4,5	Are these stages based upon 3 gauge average (WCA-3AVG, average of Sites 63, 64 & 65)?	Gina Ralph, US Army Corps of Engineers	No, these foot notes and Figure 2-2 (as stated in the figure heading) relate to the gage at Station 3-65 only. We added the gage label to the Y axis.
21	Chapter 2, Page 13, Line 353	Richard Turner is with Florida Institute of Technology.	Gina Ralph, US Army Corps of Engineers	Yes, corrected.
22	Chapter 2, Page 15, Lines 419-422	It may aid the reader to elaborate on rationale behind egg cluster counts and how the data may be used.	Gina Ralph, US Army Corps of Engineers	Additional information has been added.
23	Chapter 3, Page 18, Line 503	I believe this is the first use of acronym, "LNWR", if so, please spell out to introduce acronym.	Gina Ralph, US Army Corps of Engineers	This was the second time used; used first in Chapter 2 in Current Protocols for kite monitoring.
24	Chapter 3, Page 26-27	Is there a difference between wetland habitat types between solitary and colonial nesters? (WCA-3A versus lakes)? Is colonial versus solitary nesting related to number of woody nest sites available?	Gina Ralph, US Army Corps of Engineers	This is an interesting question, but we have not come across discussion of it in the literature.
25	Chapter 4, page 59, lines 1753-1755	Any thoughts on FWC initiative of reducing treatment of exotic hydrilla in order to maintain exotic apple snail prey base for snail kites within Lake Toho?	Gina Ralph, US Army Corps of Engineers	See earlier response above to comment # 4.

External Review Comments: Phase 2

Comment Number	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
26	Chapter 5, Page 95, Lines 2866-2869	It would be helpful to refer the reader to Chapter, Page number where the reasoning was described earlier. Some readers may only read certain chapters and may be interested in understanding where in the synthesis the discussion occurs.	Gina Ralph, US Army Corps of Engineers	A reference to the chapter and section was added.

S.J. Miller, D. Dobberfuhl, and D. Hall

From: Steven J. Miller
To: "Pomacea Project"
Cc: Dean Dobberfuhl; Dianne Hall
Subject: FW: Apple Snail & Snail Kite Report Review
Date: Wednesday, August 29, 2012 4:45:12 PM
Attachments: SJM Kite comments.xlsx

Patty and Phil:

Attached are comments on the information synthesis. The document was reviewed by myself, Dean Dobberfuhl, and Dianne Hall. Some of the comments may be somewhat repetitive but I felt obliged to include everyone's comments in their entirety.

We all agree that this document provides an extensive and thorough review of the literature concerning snail kites and apple snails. However, we also agree that this document provides more of a comprehensive literature review rather than a synthesis that provides new insights and management recommendations based on an integrated analysis of all the data. As water managers we need to have specific quantitative targets for hydrologic conditions (e.g. mean water levels, return frequencies of drying events etc.) that can be compared to hydrologic modeling results in order to develop appropriate water control structure operational guidelines. Unfortunately specific recommendations for hydrologic management that we can use are not presented but are mostly discussed as future research needs. Based on our experience it appears that recommendation to maintain February – April water levels for snails at 10-40 cm are at odds with the recommendation to maintain water levels at 20-80 cm during the kite nesting season. Raising water levels in our project areas depends entirely on rainfall and maintaining low water levels in the winter and early spring just amplifies the probability that the entire area will be dry by the end of the dry season.

We all agree that this document provides a sound guidelines for future research needs. We also strongly agree with the recommendation to form a working group that makes management recommendations regarding year-to-year water management across the snail kite habitat network. Often we base our management of the BCWMA on water level conditions in other areas of the state. Such a working group would be very beneficial in this regard. However holding water levels higher to provide refugia habitat because other areas are experiencing drought, has caused us to flood the area for undesirable durations.

For us, the most important hydrologic variable with regards to managing the BCWMA to optimize habitat for snail kites centers on what defines a drying event (related to ground elevation), how long the drying event should occur, and most importantly how frequently should the drying event occur. We have specific quantitative targets for these events that we use but we are unsure how well they are actually working. Other hydrologic targets we have relate to mean water level, frequency of inundation, recession rates and seasonality of fluctuation. In the future, perhaps our 10+ year management of the BCWMA along with the documented response of snail kites could be used as a case history of how water management has affected kite use of an important peripheral habitat. This information may be useful to other agencies responsible for managing water levels in other similar spatially small (as compared to the Everglades) habitats. Perhaps data from other more intensively studied habits could also be used to help explain the snail kite response we have

observed and help determine if adjustments to our management are warranted.

Another question we have is on the influence of exotic apple snails on the whole snail kite habitat paradigm. It is my understanding (which may be wrong) that snail kites in the past couple of years have been reproducing successfully by foraging on exotic snails in habitats (e.g. offshore hydrilla beds) that they historically didn't use. Since exotic apple snail can apparently thrive in more stable deepwater habitats (e.g. deep canals) is it possible that kites may shift their habitat preferences to take advantage of this new food resource? This could have important ramifications to current and future critical habitat designations.

This document well defines future research needs, but perhaps a more detailed section dealing with developing future funding opportunities through state and federal partnerships is warranted. Given the limited resources available in today's economic climate it may also be helpful to rank research needs in order of priority. Polling researchers might be the best way to do this since I'm sure there will be disagreement.

This is a tremendous piece of work that provides a good starting point for directing future research . However, from a management agency perspective it provides few recommendations that we as an agency can actually use at this time. We would like to see more specific recommendations for hydrologic management based upon the current knowledge base (while realizing the uncertainty associated with them) along with a proposal for using adaptive management (based upon defined measures of success or failure) to adjust them as additional data becomes available. I believe this is a goal for one of the proposed working groups and if so, this formation of this working group should be emphasized as a "High Priority" need. Unfortunately, hydrologic targets will most likely have to be developed for snail kite habitat units individually which will greatly complicate the process.

Thanks for the opportunity to comment and let me know how we can assist further with this important work.

Steve

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External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
1	Executive Summary	Although a stated purpose of this document is to describe "how to best manage hydrology and habitat conditions to support apple snails and snail kites" the executive summary lacks any specific conclusions or recommendations for meeting this objective derived from your analysis. Instead, the executive summary provides more of an overview of the information discussed in the various chapters leaving the reader to have to search through the document for this information. I would like to see specific recommendations in the executive summary along with a reference to the chapter(s) where the reader can get more details.	Steven J Miller, SJRWMD	Recommendations have been added to the executive summary.
2	ACRONYMS	BCWCA/BCWMA should be changed to BCMCA/BCWMA - Blue Cypress Marsh Conservation Area/Blue Cypress Water Management Area	Steven J. Miller SJRWMD	Changed.
3	p32, line 958	"reclaiming" should be "reclaimed" or "resumed nesting in"	Steven J. Miller SJRWMD	The suggested change was not made.
4	nesting distribution, p32	Although nesting is sporadic in the Upper St. Johns, between 1990 and 1993 (see Toland) up to 140 birds annually were documented utilizing the BCMCA/BCWMA; between 33 and 64 nests were also constructed annually. As many as 68 young (1992) were fledged.This highlights the importance of this area as a potential critical peripheral habitat	Steven J. Miller SJRWMD	We agree, and we added some of this information on the Upper St. Johns in this section on nesting distribution. We also incorporated your #8 comment below here. We added a sentence noting that in the same year that the highest number of kites/nests/fledglings were seen in SJM, the fewest number of successful nests were detected in the Everglades region.
4.5	p38, line 1122	A written reference is Meyer, K. D., and G. M. Zimmerman. 2008. Seasonal movements and habitat use of Snail Kites (*Rostrhamus sociabilis*) in Florida: a comparative study of satelite and VHF tracking methods. Final Report to the St. Johns River Water Management District. Avian Research and Conservation Institute (ARCI), Gainesville, FL.	Steven J. Miller SJRWMD	We checked with K. Meyer and was given the most recent report and citation, which includes what was provided in the 2008 report noted in this comment.
5	p37 line 1113	BCWCA/BCWMA should be changed to BCMCA/BCWMA	Steven J. Miller SJRWMD	Changed.
6	p82 line 2457	"loss"of long hydroperiod marshes as in drained? Or did you mean "extended drying" of long hydroperiod marshes	Steven J. Miller SJRWMD	The text was modified to incorporate the comment.

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
7	p 83 line 2469-2471	What actually constitutes a drydown as opposed to a drought?? Doesn't the term drydown need a definition? For example drydown may be when water is at or below the soil surface. Drought is a drydown that has intensity, spatial extent, and duration components	Steven J. Miller SJRWMD	We agree that a definition is needed. A detailed discussion of these terms was/is provided in Appendix C, and we added some additional reference to that appendix in the report. Also, we defined the term "dry down" in Chapter 2, as well as in Chapter 5 (where the comment was made).
8	p 83 line 2490	See above comment on 1992 nesting success in BCWMA. Indicates importance of less frequently used habitats such as BCWMA when drought occurs in primary nesting areas.	Steven J. Miller SJRWMD	We agree. See our response to your comment # 4 to see how and where we addressed this.
9	p89 line 2683	Could presence of large tall trees such as pines on levees influence owl predation because they provide hunting perches?	Steven J. Miller SJRWMD	This seems likely, although it was not specifically mentioned in the three studies cited here. The Martin study stated the need for more data on predation (which is inherently difficult to obtain).
10	p158 A-1 Recommendations	Is there an up-to-date detailed list of peripheral habitats? Is there a list of what peripheral habitats are in most need of restoration or protection?	Steven J. Miller SJRWMD	We are not aware of anything recent that has been compiled/published on peripheral habitats. The UF monitoring team has added areas to their annual monitoring, and K. Meyer might be able to provide some information based on the satellite telemetry work he is conducting.
11	P159 A-3 Recommendations	It is critical to water managers that quantitative targets be developed for timing , intensity, duration and frequency of drying events for their specific wetlands. Unfortunatley , gates cannot be opened and closed and and water management schedules set based on a qualitative target of "wetlands should experience periodic drydowns" . Enumerating drydown targets needs to be a priority. Developing integrated water management stategies requires specific targets so that long-term hydrologic modeling can be used to test various operational scenarios to determine which best meets the kites needs over the long term. Sounds like this type of modelling needs to be integrated over the entire snail kite habitat network at once rather than for individual units as has been done in the past. Based on your synthesis of the data --what is your recommendation for return intervals of drydowns?	Steven J Miller, SJRWMD	We agree that dry down targets are extremely important. 1) There is a recommendation in the document to address this (Chapter 11, 11-1); 2) we have tried to make it even more clear that the 3 general recommendations at the beginning of this chapter are not intended to address specific, quantitative targets but are guiding principles for conservation and management; and 3) we address your question on return intervals as a part of Chapter 9 (summary, conclusions, and synthesis chapter). We placed the discussion in Chapter 9 because there has been some disagreement about the specifics on this point.

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
12	P161 B-2 Recommendation	What is a range of optimal water level recession rates? Once these rates have been established they should also be considered by Federal agencies with regards to mandated flood control schedules. Flood control schedules that attempt to recover flood storage early in the dry season in some areas may themselves be detrimental to kites. In reality, schedules could likely be adjusted to avoid this potential negative impact.	Steven J Miller, SJRWMD	This recommendation was modified somewhat from the previous draft. In general, the information requested on recession rates is not available for wetlands throughout the kite's range. Recession rates would be in the context of specific seasonal depths in particular wetlands. Also see response to comment # 13 below.
13	P162 B-2 Recommendation	What are the recession rates specified by the multi-species transition team>?	Steven J. Miller SJRWMD	See also comment in # 12 above. We did not provide specific information from USFWS (2010) because we are focusing on the *approach* taken in the Strategy. Some concerns and issues are still being addressed in the draft Strategy. For example, some concerns have been expressed by NPS (A. Lo Galbo, pers. comm.) about the recommendations which they believe may adversely affect ridge and slough habitat. Additionally, questions continue to be raised about the Strategy during meetings on hydrologic management of WCA3A (P. Darby, pers. comm.). We and others (see comment matrix of R. Bennetts) also have concerns about using the 3A average gage (which is what the Strategy used) to represent conditions throughout WCA3A.

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
14	P 161 B-3 Recommendation	How would this information be used and at what point would this data suggest a problem significant enough to trigger a management response. A condition assessment implies a goal...perhaps first there needs to be a clarification of what constitutes a wetland in excellent condition and clarify the spatial scale being considered. (e.g 1/3 too wet, 1/3 excellent, 1/3 too dry). I'm a little confused by this one..would be great for basic research but why not just base condition on the presence or absence of successfully nesting snail kites?		We also received comments in support of this recommendation. We do not agree that this is basic research. Adaptive management embraces monitoring and we see this as a part of the monitoring process that would help answer questions on snail kite use of wetland areas. It is part of assessing the kite habitat network. If kites are not currently using an area, what is the reason? If the assesment found that conditions are good, then there is no need for management action. An absence of kites does not necessarily mean an absence of good conditions. Kites may not be there because they have not explored the area recently. Conversely, if conditions are poor (e.g., shifts in plant communities and/or declines in snail availablity) then management action (or some further data collection) may be considered in the current or subsequent years. Current and recent hydrology influence subsequent year snail availability. Even if there are snails there in one year and kites successfully nest, if water levels are too high for snails during the oviposition season, there may not be an adequate population of snails there in the following year. This information would help answer why kites are using or abandoning some areas so that action could be taken where needed.
15	P167 D-1 Recommendation	Perhaps some estimate of what the cost of such a monitoring program would be should be included.	Steven J Miller, SJRWMD	The budget would vary widely depending on the program and the project, and anticipating what these needs would be is beyond the sope of this document. Providing budgets for each of the recommendations is also beyond our scope. Although the recommendation is to monitor snails across the kite's range, we added a statement to the recommendation that areas could be prioritized by the Snail Kite Recovery / Advisory and Review Team.

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
16	P170 D-5 Recommendation	For the BCWMA maintaing water levels over the greatest spatial exent at 40 cm or less during the months of February, March, and early April would greatly increase the chance of the entire being totally dry by late May and early June. Under impounded conditions ET would drop water levels over this period at least 25 cm. We are dependant entirely upon rainfall to bring water levels in this area up. If rainfall does not start till early July or later (as is often the case) then water levels could be very low every year when kites initiate nesting or worse yet dry out after they have nested .	Steven J Miller SJRWMD	We assume you are referring to recommendation D-4 (now B-5). The intent of this recommendation is for when the wetland already is experiencing snail densities/availabilities that are too low to support foraging/nesting kites (so there are no snail kites using the area). To address the comment: 1) In the recommendation, we emphasized that it is for when there already are not enough snails to support kites; 2) We have expanded the upper limit on the 10-40 range. As we stated in the report, the 10-40 cm depth range is the best information we have so far on the depths that have yielded the **highest egg cluster production** from snails. We would also anticipate that managers would use the information in a manner that fits their specific situation.
17		The title is an overreach in that this document is probably better described as a review rather than a synthesis. There is little to no meta analysis or any new insights based on integrated data analysis.	Dean Dobberfuhl SJRWMD	We agree that we did not conduct new data analyses. This was not in our scope. Originally, the idea was to link to another CESI project (which was not funded), that would have conducted new data analyses. We have changed the title of the report.
18		While the recommendation sections are extensive, there is little quantitative information upon which to form management goals or restoration benchmarks. Managers need numbers to make resource decisions (e.g., how dry, how long, how often?)	Dean Dobberfuhl SJRWMD	This comment has been addressed elsewhere as well, as a few managers made this comment. This project was to review existing literature and form recommendations based on the literature, our review, and review from species experts and managers. For the most part, existing publications and reports do not contain quantitative recommendations that we can present. We have added a discussion of this in the report in Chapters 1 and 9 and in the recommendations chapter (10).

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
19	10, 167	Anecdotal information suggests that P. insularum is an important subsidy and perhaps an important replacement food item. An important recommendation would be to explore these dietary implications. Given the potential dietary importance of the exotic, it would useful to also investigate hydrologic conditions that promote or constrain exotics.	Dean Dobberfuhl SJRWMD	There have already been some explorations of kites eating the exotic snail (e.g., Cattau et al. 2010; see Chapter 3 under Diet, and Chapter 7). Kite nesting is annually monitored on Lake TOHO, where kites are currently feeding on exotic snails. The version of the report reviewed contained three recommendations relating to exotic snails, including to study conditions affecting *P. insularum* mating and reproduction (e.g., water depths; Recommendation 11-6). To more comprehensively address exotic snails, we have re-examined and edited these recommendations. They now include a recommendation to study parasites in the exotic snail (11-8) to assess concerns for the snail kite.
20	Chapter 8, Page 143, Lines 4209-4212	Has validated model been published yet? Sentence states that model was scheduled to be published in 2011.	Dianne Hall SJRWMD	The model has not been published yet, it is still in progress. We updated the text to note this.
21	Chapter 9, Page 148, Line 4325	Recheck timing of listing of snail kite. It might be better to simply state year when it was listed.	Dianne Hall SJRWMD	Kite was listed in 1967; we agree that it is less confusing to just state the year.
22	Chapter 10, Page 160, Lines 4689-4690	Specify wetlands "that are or have been important to snail kites in the last 30 years".	Dianne Hall SJRWMD	This language has been changed. However, wetlands important to the snail kite have been covered in various areas of the report, especially Chapter 3. We want to leave this open in this recommendation so that the approach could be applied where there is a need/interest to do so. In other places where this comment was made, we added an "e.g." statement of example wetlands and referred the reader to a specific section of Chapter 3. There is a great deal of information in this report, and we can not reproduce all background information in each recommendation. Readers need to look at other chapters of the report as well.
23	Chapter 10, Page 162, Lines 4735-4736	Specify wetlands "deemed critical to snail kites in the last 30 years".	Dianne Hall SJRWMD	See response above.

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
24	Chapter 10, Page 163, Lines 4767-4768	Where would the topographical information for areas, other than Everglades, come from? Who would pay for the elevation surveys?	Dianne Hall SJRWMD	This recommendation was intended to apply to future analyses. We have edited the language to clarify. We are recommending doing this when the information is available. Such information may be available for specific areas from individual researchers (e.g., P. Darby has such data for sites on Lakes Kissimmee, St. Johns, and Istokpoga).
25	Chapter 10, Page 165, Lines 4813-4814	Where would the money for copper testing of soil, water, vegetation/periphyton, apple snails and snail kites come from?	Dianne Hall SJRWMD	It is outside of the scope of this project to suggest who should pay for studies, and for us to develop budgets for each study/recommendation. Some work in this area (i.e., copper) is already being conducted with funding from USFWS.
26	Chapter 10, Page 165, Lines 4839-4840	Specify the "important snail kite habitats" where apple snails should be monitored on a "routine basis".	Dianne Hall SJRWMD	We combined this recommendation with the one that appeared under apple snails (as this one already referred to that one). Note that the recommendation is to monitor apple snails in the major wetland units across the kite's range. If due to logistical and monetary contraints, the areas for monitoring must be prioritized, we believe this should be done by the Recovery Team / Review and Advisory Team that is recommended.
27	Chapter 10, Page 166, Lines 4881-4882	What would be the management effects if portions of the SJM north of State Road 60 were designated "critical habitat" for the snail kite?	Dianne Hall SJRWMD	Addressing how management might be affected in each area is outside of the scope of this document. The point is that kites have abandoned some of the designated critical habitats and now heavily rely on other areas.
28	Chapter 10, Page 167, Lines 4902-4903	Who would pay for "apple snail monitoring . . . across the range of the snail kite? Would monitoring include exotic apple snails?	Dianne Hall SJRWMD	Regarding the first question, it is not in the scope of this project to identify funding sources. Regarding the second, if exotic snails are captured during snail sampling they would be recorded. The intent of this recommendation is to monitor snail populations in important kite habitats. The intent here is not specifically to monitor the exotic. See Chapter 11 for recommendations on monitoring *Pomacea insularum* .

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
29	Chapter 10, Page 169, Lines 4955-4957	What if native snail densities were < 0.1-0.2/m^2 but exotic apple snail densities were above that range?	Dianne Hall SJRWMD	From a kite's perspective it may not matter. However, there are many unanswered questions about the potential impacts of the exotic snail on snail kites, native apple snails, and wetland habitats. Increasing exotic snail populations are a concern, as are decreasing native snail populations. Some believe that exotic snail populations (increasing) are not a basis for snail kite management and recovery.
30	Chapter 10, Page 170, Lines 4969-4970	What is the trade-off to maximizing water levels for apple snails versus snail kites nesting?	Dianne Hall SJRWMD	We rephrased the recommendation to make it clear that this recommendation is for when apple snail density, and therefore snail availability, is so low that there is not enough food to support foraging or nesting snail kites.
31	Chapter 10, Page 170, Lines 4981-4983	What if habitat management practices for apple snails conflicts with water management activities for other needs?	Dianne Hall SJRWMD	How individual agencies prioritize the needs of kites and snails is up to the individual agencies.
32	Chapter 10, Page 171, Lines 5023-5024	What metrics would be used to determine when reduction or containment of exotic apple snails is "necessary"?	Dianne Hall SJRWMD	We added a few phrases in the recommendation to address this.
33	Chapter 10, Page 174, Line 5107	Who would pay for the boat checkpoints?	Dianne Hall SJRWMD	Determining funding for recommendations is outside of the scope of this report.
34	Chapter 11, Page 176, Lines 5160-5161	Will snail kite and apple snail models be validated using data sets from other wetland types (e.g., lakes or marshes in Central Florida?	Dianne Hall SJRWMD	The current apple snail model uses EDEN data for the Everglades region (WCAs, ENP, BCP). To validate the model using data sets from lakes/marshes in central FL, depth data for the areas would be needed. Darby has on-site depth data for his sampling sites on lakes and other wetlands, but they do not represent the entire wetland unit. The most recent written information we have on the kite model is from Gaines et al. (2008), which does not provide an answer to the question. However, earlier versions of the model used demography data from the kite's entire range and stage data from ~15 wetlands in the kite's range. See Chapter 8 for more detail on the models.
35	Chapter 11, Page 177, Lines 5186-5187	Given the discrepancy between radio- and satellite telemetry (Page 88, Lines 2638-2652), satellite telemetry should be promoted.	Dianne Hall SJRWMD	Several other reviewers have recommended the same time. We agree and will edit the text accordingly.

External Review Comments: Phase 2

Com-ment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
36	Chapter 11	Recommend studying the consumption of exotic apple snails by snail kites and the effects on snail kite fecundity.	Dianne Hall SJRWMD	Based on suggestions by snail kite expert Rob Bennetts, this recommendation (11-A-5) was deleted. Data on nesting snail kites are being collected annually on Lake TOHO, for example, where kites are feeding on exotic snails. There are also several existing recommendations in the report that focus on exotic snails.

R. Bennetts

United States Department of the Interior

NATIONAL PARK SERVICE
Southern Plains Inventory and Monitoring Network
Capulin Volcano National Monument
PO Box 40, Des Moines, NM 88418

IN REPLY REFER TO:

September 6, 2012

Ms. Patty Valentine-Darby
The Pomacea Project

Dear Patty,

Thank you for the opportunity to review your report on "Information Synthesis for Florida Apple Snails and Snail Kites and Recommendations for their Adaptive Management". Overall, I found the report to be generally well written given the complexity of the subject matter, and quite thorough. I am not sure if it was by direction, so I am not sure if this is a criticism, but there seemed to be little if any interpretation beyond that of the original authors. At some point, I believe that a synthesis with more in depth interpretation should be done but I do not believe that a report such as this is the best mechanism, given the likelihood for varying perspectives of the scientists that conducted the work. This might be more conducive to a workshop or series of workshops and could include an assessment of where there is consensus and where their remains disagreement.

I also would like to have seen a bit more strategic thinking in the chapter on research recommendations. It seemed to be a bit of a laundry list that I believe would have benefited by some sort of prioritization. I recognize that many of the researchers would differ in their ideas about priorities, but at the very least, I think that it would not be difficult to develop some general criteria by which priorities could be considered. These might include such things as how well does the proposed research inform management decisions, or does it help to resolve areas of disagreement among scientists.

Although there are few areas where I think that this report could be improved, I am more concerned about some of the recent science underlying this report, particular recent work on the Snail Kite. Having not worked on kites for several years, I had not had the opportunity to read more recent papers until undertaking this review, and there seems to be some general patterns that I found rather disturbing.

First, it seemed to me that much of the recent work on Snail Kites has tried to force the biology to conform to the structure of their analytical methods, with consequences that are not trivial. For example, recent papers related to movement and philopatry have relied heavily on multi-state models that measure something entirely different than what the authors seem to be alluding to in

their conclusions. I am sure that this is because sighting data from banded birds can be used for such analyses as opposed to radio telemetry which measures movement on a more continuous time scale (see below). Although such multi-state models can be extremely useful, they do not measure movement *per se*; rather, they measure the probability that an animal in a given location is at that same location at some later discrete point in time. This may seem like a subtle distinction, but it is not. For example, a kite that was in WCA3A at time 1, moved 20 times over the time interval, but happened to be in WCA3A at the second sampling time will be reported has not having moved, even though it moved multiple times. This is extremely misleading at best.

A second example of forcing the biology to fit the methods is in the paper by Martin et al. assessing natal philopatry. First, they seemed to have changed the definition of natal philopatry to conform to their analytical framework, and second they used broad regions as a spatial unit (citing use of such regions for an entirely different purpose by myself in a previous paper as justification). Natal philopatry is typically used in the context of returning to one's natal "site" (not broad region) usually to breed. Expanding sites in this context to include a broad region such as the Everglades is hardly natal philopatry for the "Everglades" kite. The substantial variation within such broad regions renders the concept rather meaningless, especially in such a spatially closed system as the network of habitats used by kites.

An additional problem with several of the recent papers on kites is that the authors also seem to have a tendency to bury their methods so deep in unnecessary jargon that it is extremely difficult to understand what was actually done. In my opinion, this inhibits the ability for readers that may not be familiar with their methods to grasp what assumptions were made, and more importantly the implications of those assumptions.

I have provided more detailed comments in the attached spreadsheet, but again, overall I found this report to be a very good start on pulling together what is starting to be a sizable volume of research. I commend the authors on their effort.

Sincerely,

Robert Bennetts, PhD.
Program Manger/Ecologist
NPS, Southern Plains Network

Enclosures

External Peer Review Comments: Phase 2

Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
1	Ch1, P1, l7	You should change this sentence to read "the North American **subspecies of snail kite** (Rostrhamus sociabilis plumbeus), **formerly** called the Everglade kite,. The correct name according to the AOU is Snail Kite, so Everglade kite is an old name... not an alternative name.	Rob Bennetts	We agree. However, we provide a bit more of an explanation on the first page of Chapter 3; even though "Snail Kite" is the official name, the old name ("Everglade Snail Kite") was not changed in the official FWS Code of Federal Regulations, and the FWS still uses the name (e.g., in the Multi-Species Recovery Plan of 1999). We have not made the change as suggested, but added "(see Chapter 3)" after the name "Everglade kite" is used.
2	Ch2, P7, l188	I recognize that you clarify this later, but I believe that this sentence should read "...(characterized as a census, i.e., a complete count; a characterization that would later be disputed)".	Rob Bennetts	OK, change made.
3	Ch2, P9, l233	I believe this sentence would be more accurate written as"1986, focusing, **at that time,** entirely on kite nesting ecology	Rob Bennetts	OK, change made.
4	CH4, P59, l1750	You indicate that *Pomacea inularum* has been at Lake Toho for approximately 10 years with no evidence of widespread destruction. I think that a lesson that has been (or at least should have been) learned from numerous case studies is that the effects of exotics does not always become apparent right away. I think that it would be a mistake to assume that since no "apparent" damage has occured, that there will not be some later in time or at different locations that may have a different ecological situation than at Toho.	Rob Bennetts	We agree. We did not mean to suggest that impacts in the future or elsewhere were not possible. Text was added to make this point.
5	Ch5, P61, l1809	The way this is worded is misleading. I think that it would be better to say "(previously described as a census)", since many, including myself do not think it is anything even close to a census.	Rob Bennetts	We agree, but used the phrase "once described as a census."
6	Ch5, P63, l1851	I am not sure if it is explicitly stated in the literature, but another problem with the count is very high inconsistency in areas surveyed both within and among wetlands. It is nearly impossible to cover all areas well, and individual observers tend to learn and develop routines that may or may not (usually the latter) be consistent with other observers.	Rob Bennetts	Incorporated comment.

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Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
7	Ch5, P79+ Multiple pages & Lines	I think that you need to be really careful and really clear about what is being measured about "movement" using radio telemetry vs. multi-state models. The radio telemetry measures movement at a temporal scale on a much more continuous time basis, such that you can estimate an actual movement from one wetland to another etc. That is NOT really the case for the multi-state models. Since these models use discrete and sometimes lengthy time intervals they are only measuring the probability that a bird at a given location is at the same or a different location at another time. Thus a bird that was at Lake Okeechobee in March of one year, then moves to 12 wetlands during the year and returns to Lake Okeechobee during the next sample period is reported as "not having moved". In other words, it does not measure anything about what happened in between the discrete time intervals even if there was SUBSTANTIAL movement. This can be extremely misleading for those that are thinking that this approach is measuring the probability that a given bird moved between time 1 and time 2.. it does not. It only measures whether or not it is at the same location in those time periods, regardless of how many times or where birds might have actually moved.	Rob Bennetts	We now acknowledge this point in Chapter 9.
8	Ch5, P80, l2395, 2403	Here again, I think that there is a high risk of being extremely misleading regarding natal philopatry. Starting with the basic definition, natal philopatry is NOT "the probability that a snail kite fledged in a particular region will be found in that same region the next year".... rather, it is the probability that a snail kite fledged in a particular area will BREED in that same area the next year. Clearly, the reason that the authors of this paper (Martin et al.) have wiggled a bit on the definition is that they do not have the data to actually measure natal philopatry as it is traditionally defined. What the authors are actually measuring using their definition is something closer to site fidelity, but even that has the caveats that are discussed above for the multi-site models. While site fidelity may be interesting in its own right, it does not have the same evolutionary implications that philopatry might have (not to mention publishibility).	Rob Bennetts	We now acknowledge the point in Chapter 9.

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Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
9	Ch5, P80, l2395, 2403, part 2	It is also a bit misleading that this assessment was done using broad regions, rather than specific wetlands. In their paper, they argue that they used the same regions from an earlier paper that I senior authored on survival. I suspect that the primary reason that they did so was one of the same reasons that we had in the earlier paper... that we did not have sufficient data to support analysis at the local wetland scale. While there are certainly some similarities among the wetlands in these regions used, there are also dramatic differences in hydrology, vegetation, management, etc... which is why Bennetts et al 1997a used specific wetlands for this topic. Thus, I would question the validity of using these broader regions for "natal philopatry". What is even more disturbing, is that after the authors clearly did not have data to support estimating "transition" probabilities relative to their natal wetland (they used a very broad region instead), in later reports, they use the results from this "regional" analysis to extrapolate inferences about specific wetlands (e.g., WCA3A) that they were unable to estimate in their original analysis. ... and after writing all this, I see that the authors of this report also identified this spatial scale issue later on (lines 2284-2287), but I will leave my comments to reinforce what the authors of this report also stated.	Rob Bennetts	Acknowledged. We referred to the point of this comment in Chapter 9.
10	Ch5, P81, l2417	The authors of this report correctly point out that the emphasis on estimating effects on population change has been on water stage, rather than food. As one of the authors that contributed to this emphasis, I would be the first to admit that the emphasis on water levels was primarily as a surrogate for food, which has traditionally been much more difficult to measure directly. Since I doubt that kites are primarily responding to drinking water or bathing, food availability would clearly be a more direct and better measure to emphasize when feasible.	Rob Bennetts	Acknowledged.
11	Ch5, P83, l2493	It is probably worth noting that the same criticisms about the annual count (e.g., as a function of effort) apply to numbers of nests. Thus, our reports of statewide numbers really reflect the number of nests counted… not the actual number of nests. And here again, I would be the first to acknowledge that our effort in finding nests varied dramatically, and was not the emphasis of our efforts	Rob Bennetts	This idea was addressed in one of the recommendations, and we have added it to the report in Chapter 5 where it was commented on and in the text introducing Table 3-1 in Chapter 3.

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Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
12	Ch5, P85-86	I found the discussion of demographic metrics relative to habitat degradation/inundation quite disturbing. Although the authors of this report indicate that the analyses by Martin et al. (2008) were exploratory, I find this to be an extremely generous qualifier. Aside from critical assumptions (e.g., a pre-breeding census), which their own data call into question, the environmental hypotheses tested are ambiguous and completely confounded. For example one hypothesis is habitat conversion due to management and another is based on the frequency of "moderate" drying events. What Martin et all do not make clear is that the management hypothesis is directly related to the frequency of drying events ... the same thing that hypothesis 2 is based on. These are completely confounded. I am sorry to be so blunt about this discussion, but I found the underlying analysis from Martin et al 2008 to misleading at best. Thus to introduce this as guidance for management is quite disturbing.	Rob Bennetts	The Martin et al. (2008) paper includes analyses of hydrologic conditions that included relatively extreme high water events (1990s), as well as more recent (2001 and later) drying events (what is "extreme", of course, is debatable). In their conclusion they point out discrepancies between their results and those reported earlier from Bennetts (1998). In addressing comments by Z. Welch on our discussion of this same paper in the report, we ask if some of this discrepancy reflects the lack of drying events during the period of study reported by Bennetts. We also point out that snail populations appear very low in wetlands where in the past relatively large numbers of kites had been observed (e.g., 3A and 2B in the 1990s). This could also produce misleading results (e.g., hydrologic conditions may change, but if snail densities are very low kites may be responding to the snails, not the hydrologic conditions). Having said that, we modified the text in Chapter 5 based on many comments by Z. Welch to reflect the Martin et al. (2008) conclusions, but also added material in Chapter 9 that incorporates some of the concerns raised by this comment (which we had also raised in the draft Chapter 5, but have moved to Chapter 9).
13	Ch5, P87, l 2602	I agree entirely with questioning the use of CA3AVG to represent conditions south of I75....and would go so far as to say that this is outright misleading if readers do not understand that the average is being strongly influenced by a part of 3A that is not really relevant (i.e., not used by kites), and has dramatically different hydrologic influences to inputs, flow, etc. as a result of a being separated by a major highway.	Rob Bennetts	Acknowledged.
14	Ch5, P88, l 2638-2652	The findings by Meyer et al, is an extremely important point. We acknowledged in our previous reports the worrisome amount of censoring when a radio was missing, but we could not confirm whether the bird was alive or dead. The data from Meyers indicate how biased such estimates can be as a result of censoring, and should call into question the overall estimates of survival from radio telemetry data when substantial censoring occurs (including data that I collected) depending on how censored animals are treated.	Rob Bennetts	We incorporated the comment on telemetry in one of the recommendations in Chapter 11. This comment and those from several other reviewers support the use of satellite telemetry rather than radio telemetry.

External Peer Review Comments: Phase 2

Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
15	Ch5, p100, l3019	The description of 30-40% open water mixed with scattered emergent or floating vegetation was made by myself based primarily on a very simplistic imagery classification and GIS analysis in a limited area of WCA3A. Having since gained much more experience In different areas, since that report, I am not so sure how well it stands up as a generalization... which probably depends on how open water is defined.	Rob Bennetts	Spoke with the reviewer on this. Rather than delete the information, we noted that the estimate was in a portion of WCA3A only and may not make a suitable generalization. In Chapter 3, also pointed out the estimate was based on simplistic imagery (as stated by Bennetts).
16	Ch5, P102, l3058	I am not so sure that the selection of alligator weed and torpedo grass over pickerel weed is merely a function of visibility. In the shallower areas, snails may be more likely to be near the surface, where they are available to kites, even if the densities are greater in the pickerel weed. So it could be visibility, where the snails are relative to the surface, or both.	Rob Bennetts	We modified the text to acknowledge the potential effect of depth.
17	Ch7	Although it is scattered throughout this report, I am making a generalization here because this chapter deals directly with the topic. Throughout this report, the authors emphasize the importance of understanding (and the lack there of) snail availability in relation to Snail Kites. I agree completely with the authors about this assertion. Much of what is measured related to Snail Kites (water levels, vegetation, etc.) is really a surrogate for snail availability and without keeping this at the forefront of our thinking, it can be quite easy to misinterpret spurious relationships in the context of management. The exception to this is nesting habitat which certainly includes, but is not limited to, snail availability.	Rob Bennetts	Acknowledged. However, note that the review by Z. Welch held a different perspective on the relative value of data on snail availability (as measured by density) and hydrologic metrics (stage data, deviation from stage, depths, etc.). From our view, this points out a need to distinguish the relative influence of hydrology, vegetation and prey density (which combined, contribute to availability) in analyses that have yet to be conducted.
18	Ch7, P131, l3869	Although I am generally always happy to take credit, it should probably be noted that our approach to estimating snail densities in $1m^2$ throw traps was based on work conducted by Owre and Rich.	Rob Bennetts	A sentence on Owre and Rich has been added.
19	Ch10, P159, l4650+	I agree entirely with the idea of establishing some sort of advisory team, but I would caution against having that team dominated by persons that have a vested interest (including financial from grants, etc.) in the outcome of recommendations. It is a well known fact that researchers tend to promote their own research, and the criteria for recommendations should be based on what is in the best interest of the species, not the researcher.	Rob Bennetts	We agree with your statement.

External Peer Review Comments: Phase 2

Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
20	Ch9, P155, l4524	The idea of species having contradictory hydrologic needs, overlooks the fact that these species have coexisted long before we started "managing" the system. I believe that a better way to think about it is that rather than needs being contradictory, the needs of individual species are met through a complex system of spatial and temporal dynamics, and that even though all species may coexist, it does not mean that they occupy the same location at the same time. So for example, the drying of an area may favor wood storks or some other species at the time of drying, but even though kites may move during such a period, that drying also ensures the long-term health of the habitat even for kites.	Rob Bennetts	We incorporated the comment into the Chapter 9 text.
21	Ch10, P161, l4707	Although I generally agree with this recommendation, I get a bit nervous when the criteria is stated in such a way as to imply ensuring that water levels will be maintained during the entire breeding season. I think that a better way to phrase it is to strive for reasonable water levels at the start of the dry season that mimic the natural system in such a way that they may be likely to persist during the breeding season under typical drying rates, but in no way is that ensured. Let's face it, under a natural system some areas DID dry out during the breeding season. I think that always trying to make sure that water levels persist thought he entire nesting season will lead to a tendency to keep an area too wet, and ultimately degrade the habitat as has been repeatedly exemplified in the water conservation areas.	Rob Bennetts	We agree. We incorporated your language into the recommendation.
22	Ch10, P163, l4767	I agree entirely with this recommendation. The subjective use of terms like "drought" (including by myself) have caused considerable confusion, and the authors of this report have done a service by their treatment of drought semantics.	Rob Bennetts	Acknowledged.
23	Ch10, P164, l4783	I have mixed reaction to this recommendation. I certainly understand the need to protect nests and snails from destructive practices, but having exotic plants take over, may be even more detrimental in the long term. I would prefer this recommendation to be stated something like ..." explore and advocate methods or timing of exotic plant control that are less likely to result in harm to kite nests or apple snails."	Rob Bennetts	We kept the recommendation, but incorporated the suggested language.
24	CH10, P64, l4806	I am not very convinced that refuge need to be in close proximity to the areas being managed. I suspect that in such situations, kites will leave the area entirely, rather than find local pockets of refugia.	Rob Bennetts	We have deleted this recommendation.

External Peer Review Comments: Phase 2

Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
25		*Note: nothing was entered here.*		
26	Ch10, P166, l4848	While I agree that analysis of movement is biologically important and relevant, I am far less sure that the multi-state modeling approach currently used gets the information needed, even if conducted at a wetland specific scale. Measuring the probability that a given bird observed at a given wetland in one year is at the same or another wetland unit in the next year is NOT the same as monitoring movement, and I believe that it gives a very ambiguous measure which could easily lead to questionable conclusions.	Rob Bennetts	We have deleted this recommendation and addressed the issue in Chapter 9.
27	CH11, P177, l5176	I believe that the information needed re mortality should be focused on periods of drought and conducted in conjunction with a more general study using satellite telemetry (see below). A focus on mortality in general, although interesting, would not likely have information that is very useful for management.	Rob Bennetts	This research recommendation was made based on information presented in Bennetts et al. (1994). We folded this recommendation into recommendation 11-4 to address the reviewer's comment.
28	CH11, P177, l5186	Having led the telemetry study cited as a reference for this recommendation, I am convinced that the best way by far to obtain the information needed is using satellite telemetry. Simply put, traditional VHS radios will not enable sufficient detection in the myriad of potential nooks and crannies needed to be surveyed. Even with VERY extensive (and expensive) searches by aircraft, we were only marginally successful in locating birds that had dispersed from the major known habitats. Thus, I would HIGHLY recommend expanding the ongoing efforts by Meyer, rather than starting a new study, especially using VHS radios.	Rob Bennetts	Several other reviewers have also recommended satellite over VHF transmitters. We agree and will edit the text accordingly.
29	CH11, P178, l5217	I am not convinced that such a study is very feasible, and even less convinced that it would be that useful. Understanding the causal effects on fecundity would be extremely difficult to isolate, and anecdotal evidence suggest that high fecundity occurs during years of high food availability. This is one where I would tend toward making a leap of faith that if food is highly available, that kites will produce more broods and let's save the limited funds for more urgent issues.	Rob Bennetts	We agree with the reasoning behind the comment and deleted the research recommendation. The connection between snail availability and production of young is addressed by recommendation C-5 (previously Rec E-2).
30	CH11, P179, l5230	This is another one that I question whether it is of high enough value/need to warrant a study. I know of no evidence that roost sites are limiting and I suspect that if a roost site is destroyed that kites will quickly find a replacement. It is not that it would not be interesting, I just think that there are more urgent issues for which limited funds could be used..	Rob Bennetts	We believe that this would be an interesting and perhaps informative study, but we agree that it does not rise to the importance of other research recommendations. It was deleted.

External Peer Review Comments: Phase 2

Comment No.	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
31	CH11A	I would like to express a more general criticism/suggestion for this chapter. After reading through the various recommendations, it seems that this section is to some extent (not entirely) kind of a laundry list of recommendations some of which have been lingering in the literature, some of which represent the interest of researchers, etc. I really believe that a more strategic approach is needed. In my thinking, this section should emphasize research that has the greatest implications to management and/or where there has been the greatest uncertainty or disagreement among scientists. In my view, an arena that fits both of these criteria are what happens to kites during droughts. Where do they go, what is happening to the availability of refugia, and how does this relate to mortality vs temporary displacement from the major habitats, etc. And, although I am pointing this out as part of the "kite" research needs, apple snails are in integral part of the issue. Without a more focused treatment of research needs, I am fearful that any research dollars will be wasted on pet projects that will have little influence on the conservation of these species (the kite and native snails). Some sort of prioritization is needed. Although getting agreement on such prioritization might be a daunting task, I think that it is at least possible to get agreement on the criteria by which research needs could be considered.	Rob Bennetts	A similar comment was made by two other reviewers. While we did not prioritize the research recommendations, we added discussion of the prioritization process in the introduction to the chapter. We also recommended that the prioritization be conducted by the Snail Kite Coordinating Team (whose formation is recommended in the report).
32	CH11, P180, l5273	You suggest the need to explore the occurrence of parasites in native apple snails. I agree with this recommendation, but wonder why you limit this to native apple snails given the increasing occurrence of non-native snails.	Rob Bennetts	Agree. We have added the sampling of exotic snails to this recommendation.

Z. Welch

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
1	Overall - Cons	The information doesn't seem to be synthesized succinctly enough, making it cumbersome and hard to read. For example, why does this review include details from studies about what the most parsimonious or second most parsimonious model was, and even the symbols used in their models? Shouldn't a review provide a general take-home point of the research? There's also a discrepancy between how much time is spent discussing various studies. Some appear to be reproduced almost in their entirety, and others are simply cited without much detail at all as to how authors came to that interpretation (Martin et al. 2008 vs. Darby et al. 2005, 2009, for example). Additionally, the reviewers appear to caution the readers against the findings of several studies, most notably Martin et al. 2008, by criticizing the analytical methods, environmental variable selection, etc. Generally a review doesn't include an endorsement of one study's findings vs another, especially when the reviewer is also author of the majority of reviewed material.	Zach Welch	We agree that some sections of the report are relatively long; in some cases we believed it was useful or necessary to provide detail. As far as parsimonious models and symbols--those particular manuscripts (e.g., Martin et al. 2008) focused on those aspects of the analyses, and used many symbols which made the manuscript challenging to follow (also see comments and cover letter by R. Bennetts). We included them to represent what the authors presented. We have pulled some of that material out, and leave the reader of this report to delve into the details on their own. We do not agree with the reviewer's assessment of our criticism of some of the papers. Pointing out a discrepancy is not a criticism. Where we do point out some issues, it is because older published works had different results or conclusions. Also note that a review by a kite expert (R. Bennetts) agreed with some of our points relating to a few recent snail kite manuscripts. Our role in this review is to point out those contradictions or differences, try to explain why different conclusions might be made, and point out that there are differences of scientific opinion that should be resolved. The reviewer alludes to one of the authors (Darby) having written the majority of the reviewed material (which is not correct, in that Darby has fewer than 20 publications cited, and they focus on apple snails). We cannot change the fact that there have been relatively few authors on particular subjects. The report has been reviewed by ~15 individuals, many already familiar with the kite and snail literature, and no such issue was raised. One of the reasons we offered draft reports to so many different reviewers was to obtain reviews from a representative audience. We did not "endorse" findings of the reports and publications, but we did point out questions that we believe could affect interpretation of important information.
2	Overall - Pros	There is a lot of information reviewed here, and the reviewers appear to have done a thorough job of finding pertinent literature. I was particularly pleased to see a call for more research into what drives snail reproduction, as I think that's that number one priority for research right now. Until we know how to grow snails, we can't make well-informed decisions about managing critical kite habitats.	Zach Welch	Acknowledged.
3	CH 2; Line 308	If Harns marsh is included (it only recently started being surveyed) as a surveyed wetland, there are others that should be mentioned. Grassy Waters Preserve has been monitored for a long time, for example, and the STA's longer than Harnes. They also do Hungryland and Rotenberger WMA's.	Zach Welch	What appeared in the report was based on the most current annual monitoring report we had at the time (annual report for 2010). We have edited the text according to the now available annual monitoring report for 2011, which presents some different information for areas monitored. It should also be acknowledged that this will likely change as kites continue to shift their distribution (for example recently foraging and nesting on Lake Runnymeade).

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
4	CH 3; 593	Any notion that adult kites don't perch hunt is outdated.	Zach Welch	That one sentence was just presenting what one researcher (Beissinger) observed, but we agree with the comment. We removed the sentence. The next sentence provided details of one report showing perch hunting is less frequent, but may not be considered rare.
5	CH 5; 2065-2068	The previous paragraph just highlighted how young productivity dramatically declined in 1999, and never went above 50 after 2000. Shouldn't this sentence state how the nest production has been really low since 1999, not 2002? This appears to be priming the readers for the apparent drop in snail densities that Darby et al. (2005) reported after 2002, but kite production declined prior to that.	Zach Welch	Yes, it should say 1999, which is a reference year in the previous sentence. The phrase now says "many fewer young produced since 1999". This sentence was not to prime readers for the connection to low snail densities after 2002. Also note that Darby et al. (2005) showed snail densities were still relatively high, at least in southern 3A, in 2003. Snail density data were not available for all the areas of 3A in which kites had nested prior to 1999, so we cannot say what trends there were in snail density.
6	CH 5; 2410-2413	I don't understand why this sentence is here. It appears to be faulting the researchers for looking at wetland unit vs. wetland region. But the fact kites move within a wetland region between wetland units was already established in the paragraphs above by both Martin and Bennetts... the Martin 2007c paper combined wetland units into wetland regions for the fact that conditions can vary between units within a region from year to year, and can make natal philatropy seem low. The last sentence here seems to be missing the whole point of why natal philopatry was looked at by region instead of unit... because if you only look at unit, it appears that kites have lower site philatropy (as Bennetts reported) when in fact the birds are still close to home, but minor changes in conditions may have moved them next door. The boundaries between wetland units in the everglades are man-made, and a bird born in 3A may still consider 3B part of its home landscape. Looking at regions was entirely appropriate and the whole point of the paper was to compare philatropy as described by region vs unit. And yet this last sentence appears to be cautioning the reader against the results of the study, I assume because they were perceived to conflict with Bennetts' earlier findings. This isn't the only place in the report that the reader is warned against interpretations from authors.	Zach Welch	The point of this sentence is that different conclusions are being drawn based on the way wetland units were grouped into regions. It is valid to point out that there are considerable differences in snail availability and habitat conditions between wetlands within a region at any particular time. This cannot be disputed (there are plenty of data to prove that point, e.g., EDEN, and reported snail densities, and kite distribution over time). We are not faulting any researchers; again, where discrepancies are found between different studies, we try to point them out. Bennetts (see comment matrix) agreed that some of these discrepancies reflect study design or analytical approach, and we believe it is useful to point them out here and in other places in this document.

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
7	CH 5; 2485	The section says 1992-present, but then you start off with 1992-1997 I think. You say 95 and 97 were the highest numbers of successful nests in the glades region, but 98 was higher and isn't referenced. If you're not addressing 98 until the later section, you should be more clear about which years you're addressing where. Besides, there's no mention of the 98 high nesting numbers in the following section. Why were 95 and 97 singled out? You also refer to Table 3-1 but that starts at 1996, not 1992.	Zach Welch	We do not agree. This section does include information from 1992 through the present. The 1992-1997 time frame refers to a specific publication that we cite, but we continue to go on and cite more recent publications (e.g., by Martin et al., Cattau et al.) that report on conditions from 1998 onward. 1995 and 1997 refer to relatively wet years as characterized in Bennetts et al. (2002). Table 3-1 includes those data, so it is a valid table to reference. No changes made since the text in this section is consistent with the title of the section.
8	CH 5; 2516	We don't know that they avoided nesting in 3A in 2001 because of low water. We suspect that was the case, but they nested there in 2011 when water was even lower. Survey results from the time (Welch pers obs) typically found over 100 kites in the western, cypress edge of 3A in the earlier breeding season of 2001, but no nesting was found. Search efforts were also very minimal in 2001 compared to other years.	Zach Welch	We agree regarding making a direct connection between lack of nests in 3A in 2001 and the relatively dry conditions, especially given your pers. obs., so we deleted the sentence. In the next paragraph, Martin et al. (2008) describes the negative impacts of these hydrologic conditions on kite reproduction in general (although your pers. comm. also suggests an issue of search effort).
9	CH 5; 2529	This paper is overly critiqued, and the findings misinterpreted. The reviewers appear ready to disregard the results of this study because of the author's use of the term "exploratory" when describing the analsyes. Exploratory statistical methods are simply those used to detect patterns and/or trends in a large dataset. The reviewers use of quotes and subsequent cautioning against the study's findings appear misguided (2586). For example, many of Darby et al (2005) data regarding trends in snail densities or egg laying in 3A aren't analyzed statistically at all, even using exploratory methods, and yet are cited throughout this review without any cautionary warnings of how the results should be used... despite such warnings in the original source (Darby et al. 2005). More on this later.	Zach Welch	The authors themselves made note that implications were made, but they qualifty this with "although exploratory in nature". We did not misintrept their own qualification of that fact. We were not overly critiquing the paper -- it was a long paper with many details that we (and others, see Bennetts review cover letter) found challenging to follow. We have shortened the presentation of the Martin et al. (2008) paper in Chapter 5, and point out any discrepancies as Martin had noted (e.g., with older literature). We now make any additional comparisons or explanations (e.g., bringing up snail densities reported by others) in Chapter 9. Also see our response to comment 45, which also addresses the Martin et al. (2008) paper. Also see several other responses to comments regarding high water influences on snail eggs (comments 23, 24, 25, 26, 54). Also see review comments by Bennetts.

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
10	CH 5; 2640	Survival was estimated as the percentage of transmitters that couldn't be relocated? Why was a lost signal counted as a mortality? Given that nobody ever estimates survival by calculating the percentage of lost radio transmitters, I don't see how this study shows anything except that kites are capable of moving outside of their natal areas, which is well documented. This whole section seems out of place.	Zach Welch	Nowhere does it state that survival was estimated as the percentage of transmitters that could not be picked up. The point is that when you can not account for transmittered birds (i.e., "lost birds"), you have to censor them from your data for certain analyses, such as estimates of survival. Since birds were wearing both types of transmitters in the Meyer study, he was able to address interpretations of survival using both types of transmitters. With the VHF transmitters, survival would have been estimated to have been lower than it actually was (due to lost birds which would have to be censored). Also see comment #14 from Rob Bennetts (comment matrix) on this same topic.
11	CH 3; Table 3-1	you have total nests in parentheses instead of nests with eggs. That's opposite of the rest of the table and makes it look like there were more nests found with at least one egg than nests without.	Zach Welch	We rechecked Table 3-1 to the original sources of information, and what you have stated is incorrect. In all cases the numbers reported were said to be active nests (those with at least one egg). Unfortunately, there are discrepancies between numbers of active nests reported in the V. Dreitz reports and the Martin et al. 2002a summary and the USFWS (2007) table. We went ahead and presented all of the numbers; for those years (1996-1999) where only one number is presented, there was no discrepancy. What is really important in this table, however, is the relative number of active nests between areas and years. We added some additional notes to the table to try to better explain the discrepancies.

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
12	CH 5; 2587	This is an absolute misinterpretation of Martin et al (2008)'s findings and recommendations. This review interprets the study's finding as suggesting "managers should reduce the frequency of moderate drying events in managed wetlands used by snail kites", and says it contradicts earlier studies that recommend drying frequencies of 1.9-3.8 yrs (Bennetts et al 1988a). In actuality, Martin et al (2008) suggested that the current (then) frequency of moderate and extreme drying events in 3A (5/7 yrs - actually it was 99, 00, 01, 02, and 04) could possibly be more detrimental to the kite population in the short term than any longer-term habitat changes that might occur. They went on to state the importance of maintaining periodic droughts, warned about the negative effects stabilization can have on habitats, etc., though they are criticized in this review for apparently not recognizing that. The point of the research was that while periodic dry-downs are good for the habitat, having too many moderate and severe droughts too close together have the potential to severely limit kite reproduction in the area, and even adult survival. Recall this paper was also written when the population had decreased approximately 50% in the last couple years, and the Kissimmee Chain of Lakes and Okeechobee were not producing many young at that time. i.e. the outlook was was extremely dire. So the emphasis of the paper was on providing immediate, most beneficial conditions for kite reproduction in 3A. This review appears to interpret the paper as suggesting that all wetlands important to kites be managed at dry-down intervals of 1 every 7 years, and that's not what was suggested.	Zach Welch	We do not agree that this is an absolute misterpretation. See Martin et al. (2008) p. 35, 2nd paragraph under Discussion, continuing to the top of p. 36. They point out a discrepancy to older reports (they refer to Bennetts 1998, his dissertation, but we reference Bennetts et al. 1998). It is also valid to point out that moderate drought conditions may result in increased snail densities (and therefore availability, in appropriate foraging habitats). We do agree that we should emphasize in our report that Martin et al. (2008) points out the shorter-term negative impacts on reproduction (top of p. 36 in Martin et al. 2008), and we have changed the text to reflect that point. We maintain that there are issues in interpretation of the Martin et al. (2008) analyses, in part because of questions about how to characterize a "drought." Our perspective on this is validated by another review that was completed at the same time as this review (see comments by Bennetts). We also cited Martin et al. (2008) with regards to habitat degradation (the statement about us not recognizing this is inaccurate, e.g., see Lines 2581, 2806, 2885, 4481 in the "agency" draft). We have moved most of the discussion of any discrepancies related to the Martin et al. (2008) paper to Chapter 9.
13	CH 5; 2592	I would argue this statement is quite a stretch. What the 2 cited sources primarily rely on is one site's egg cluster counts (site 10, near Tamiami), which was either 1 or 2x50m long transects in 2002 (the authors don't report whether they had 1 or 2 transects, nor report any variation around the mean). Other sites were added after 2002 and all had much lower egg counts, but the only transect(s) measured in both 2002 and beyond were at site 10... and they were only counted 3 times in 2002. Do 3 separate days of counting egg clusters along one or two 50m long transect(s) in one location of southern 3A really qualify the authors to state that 2002 was the "most productive" year from 2002-2005? Additionally, Darby et al. (2005) even states "These data were not analyzed statistically because we had incomplete data sets, there was often no water depth data collected when eggs were counted, and there was too great a range of conditions to make meaningful comparisons between sites. We did, however, make qualitative comparisons between sites and years (for sites with multi-year data) in an effort to understand the effects of differences in water levels on the timing and overall production of egg clusters by apple snails." If the readers are cautioned against using the results from studies using "exploratory" statistics, why are they not cautioned from the results of studies using none?	Zach Welch	Discussion of discrepancies in the intrepretation of some of these patterns has been moved to Chapter 9 (as have most discrepancies found in the literature and/or reviewers' comments). Regarding this topic, as it does apply to Chapter 9 in the revision, we said nothing about egg cluster counts from any transects in this sentence. Throughout the document, we have clarified the text to describe that relatively high snail densities and egg cluster counts were indeed associated with relatively lower water conditions (or conversely, that relative high water can negatively impact eggs). A decrease in snail density in 5 sites following the relatively wet year was also presented in Darby et al. (2005). It is more complicated than just egg counts (which influence the NEXT year's snail density), but we have also referred to other parts of the document to explain these associations in more detail. We have also added statements in Chapter 6 to more clearly point out that these connections (although directly observed) were based on limited data (which is why we address this in Research Recommendations).

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
14	CH 5; 2595	The drought status was based on statistical deviations from a norm. The whole Everglades landscape has a gradient, and when one area is dry, some are drier and some are wetter. So while one particular spot on a landscape may still be wet, it doesn't mean there's not a drought. The most common way to determine whether an event is considered a drought is using deviations from stage data. Since 3A was the focus of the paper, and gauge 65 had 2001 as the lowest year since 1990, I don't see why that wouldn't be a worthy extreme drought designation. See my comments on Appendix C for further discussion of this unwarranted criticism.	Zach Welch	Bennetts (who developed the use of the deviation from the norm to describe hydrologic conditions for kites) agrees with the concerns we raise here and in Appendix C (see comment matrix). The need to focus on depth data (rather than stage data) has been described by other avian ecologists studying the Everglades (see Beerens et al. 2011). Darby has other pers. comm. (e..g, from Multi-species meeting notes) that also describe these problems with using stage data (or deviations from stage) to try and understand avian ecology.
15	CH 5; 2649	No, Meyer et al. (2009) didn't raise any questions about "potential influence of hydrologic conditions on detectability that might influence survival estimates." First of all, how hydrology affects kite movement was well covered earlier in the review paper, and studied by several authors. Secondly, survival estimates are NEVER based on whether radio transmitters are out of range or not. This study didn't make any robust estimates of survival, detectability, or anything. It was designed to simply follow kite movements. It showed that when kites move larger distances, they can move out of range of radio transmitters and that you may need to expand your search area. Fortunately, no studies to date have analyzed radio telemetry results like Myer et al. (2009), so there are no valid questions raised about detectability and how it's been used in other studies.	Zach Welch	The text was not saying that Metyer et al. (2009) directly raised questions...It said that the results raised the question. This was a connection that we (authors of the report) made. In order to eliminate any confusion we added that 'in our review...' we concluded this could be an issue. Both authors (PCD and PLVD) conducted flights tracking VHF transmitters on kites, and we understand that aerial coverage, which is certainly better than coverage by airboat, still has significant limitations. This results in some missed signals and missed birds (R .Bennetts concurs). This is consistent with Meyer's work. Regarding your second point, see our response to your comment #10 above. Also see comment # 14 in R. Bennetts' comment matrix. Regarding the Meyer study, the sample size was small, but it did show how censoring birds when the signals are lost (you do not know if the birds are dead or alive) can affect estimates of survival, for example. We disagree with the reviewer on the overall usefulness of the Meyer study and its findings. We have found the movement results of the study useful and interesting, and additional information has been gained using satellite transmitters. This work is on-going, and continues to support the conclusions found in the 2009 (now updated to 2011) report.
16	CH 5; 2665	UF researchers have put cameras up by nests to determine actual causes of failure. Collapse in non-woody substrates has apparently been highly overestimated in the past.	Zach Welch	In Chapter 2 in the section that describes the annual kite monitoring program we mentioned that cameras were to be used for this purpose (described in Cattau et al. 2009). We have located a brief discussion of the preliminary results of this work, presented in an appendix of Reichert et al. (2011). We have added a few sentences on their findings to our report here (and we updated the note in Chapter 2).

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
17	CH 5; 2669	Snyder 1989a apparently had a bunch of nests in poor cattail, because the last 6 yrs or more of the nesting activity has occurred primarily in non-woody substrates and nest success has been quite high.	Zach Welch	We reviewed the text and found no changes that need to be made.
18	CH 5; 2817	Water levels were not low in 3A in 2008. 2001, 2007, 2009, and 2011 were low. 2008 was dry in Okeechobee because the lake didn't fill after the record low in 2007, but it wasn't drier than normal in 3A in 2008 (>9.5' CA3AVG in April 2008). Low water conditions in 2007 might explain the lack of nesting in 2008 if the snail population hadn't recovered, similar to poor 2012 nesting in 3A after the low water in 2011.	Zach Welch	We deleted the phrase "possibly due to low water conditions."
19	CH 7; Fig 7-1	This whole relationship seems based on the zeros found at low snail densities. How were the sites selected? I suspect that there are many km2 in 3A where no kites are found, but there are still some snails.	Zach Welch	See Darby et al. 2006 for details (this graph comes directly from the published manuscript); even exclusion of the zeros results in a significant relationship. The "no kite" sites were in the vicinity of other sites which did support foraging kites.

External Review Comments: Phase 2

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
20	Darby 2005	I've always had concerns about using the limited egg cluster data (one site, 10) to make broad inferences about water depth requirements for snail egg production across the state. The biggest problem is that the low 2003 egg production at site 10 vs the high production in 2002 is attributed (by the authors) to the fact water levels were lower in June 2002 than 2003. But peak production occurred in March of 2002, and water was actually DEEPER from Jan-mid March of 2002 than in 2003... the exact opposite of what is suggested. How does a lower May-June water level have anything to do with egg production in March, which is where the biggest difference occurred between the 2 years? If low spring water levels were as important as suggested by Darby et al. 2005, then 2003 should've had even higher March egg cluster counts than 2002 (because the water was lower), and would've started to trail off after that. Perhaps the colder temperatures experienced in the spring of 2003 (as the authors even pointed out) had much more to do with low production than is given credit for. It's possible the results of this one site and one study have been given too much weight in interpreting snail hydrological needs for reproduction. It seems fairly obvious that if the single site observed in 2002-2003 actually did represent a trend at a larger scale (which we have no way of knowing) that the cause occured prior to March of 2003, not after. If the spring was colder in 03, for example, and the water didn't recede much after March even as the water warmed, maybe the combination of cold weather and slowly receding water levels delayed production. Additionally, the authors make general recommendations based on site 10's data, which is a relatively deep site at the extreme southern end of 3A, where water is likely impounded by Tamiami Trail. So suggestions that low water like what occurred in 2001 was great for snail production, that should likely be constrained to "in the extreme southern end of 3A". In fact the authors found the lowest snail densities in their 2 most northern sites, perhaps because 2001 was much too dry up there. And again, if the drier conditions experienced in the south were good for snails in 2001, then why aren't wetter years good for snails farther north? Again, the authors even found that between 2003 and 2004 snail densities INCREASED in their northernmost site but decreased in the 3 southernmost sites. Perhaps the biggest issue is magnitude of variability between years, where optimal conditions for snails or kites occur at too great a spatial distance in 3A from year to year, thereby rendering the majority of the system in a fairly poor condition. Frequent droughts knock down densities in the north, followed by frequent high water that knocks them down in the south.	Zach Welch	Here the reviewer is commenting on Darby et al. (2005), a report that shows an association between low egg cluster counts while monitoring snails and eggs in WCA3A in 2002-2004. Where the reviewer has made specific comments to a line number in this (Pomacea Project) report, we have addressed this issue (see response to comments 23, 24, 25, 26, and 54). As far as hydrologic conditions, depths in 2002 did fall to lower levels in 2002 vs 2003. Peak production in 2002 may have been influenced by warmer temperatures, but by May-June, temperatures in 2002 and 2003 were very similar, and yet egg cluster production in 2003 was still very low (**despite relatively high snail densities**). [Darby et al. 2009 emphasizes the importance of looking at egg production on a per capita basis]. There is likely (and not surprisingly) a temperature effect, but what is being shown in Darby et al. (2005) is that water depth also influences egg cluster production. Responses to other comments also address this topic. The reviewer asks about water conditions further north; yes, more eggs in general and earlier in the season were associated with shallower water associated with Site 11 as compared to Site 10 as shown in Darby et al. (2005). Unforunately, very little data has been collected to show hydrologic effects on egg production in more northern reaches of 3A. However, Darby et al. (2009) did show per capita egg production to be greater in shallower water sites in a 2005-2007 study, adding evidence to the idea that relatively high depths (percisely what that means requires more work) can suppress egg production. Also see references to Gleason et al. (1975). We agree that there could be a problem with frequent drying events causing problems in portions of 3A (higher ground elevations) while relatively high water in southern 3A can have negative consequences to snail production (also see Kitchens et al. 2002). In Chapter 11, we recommend controlled studies to more thoroughly assess the role of seasonal water depths on the influence of egg cluster production.
21	CH 7; 3953	But how many kites were there back then? 4000? 3000?	Zach Welch	This sentence refers to specific locations of nests in the vicinity of foraging areas where Bennetts et al. (1988) sampled. The point is, snail density influences local use by kites, including nest numbers. This has been shown in a new manuscript (in prep) which is now referred to in the recommendations chapter. The state-wide total numbers of kites was not critical to this point, it is just kite use of 3A and associated snail densities.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
22	CH 5; 2947	2947 - I read the paper differently. Although confusing, I thought they had 159 total nests in non-woody substrates, 94 of which were supported with artificial structures. The authors assumed all those would have failed. Of the remaining 65 nests, 3 were successful. I think the authors were very presumptuous about the fate of the nests had they not intervened, and I think the location of the nests (cattail on Okeechobee) may have had much more to do with any collapse than the substrate they were in. Fetch on Okeechobee can be quite extreme, and if the majority of nesting cattail was near open fetch areas of the lake, failure could have been quite high. But the majority of nests have been in non-woody substrates now for >5 years, and success has not declined. It's not unusual to have >50% nest success in non-woody substrates on the Kissimmee Chain, for example. The reviewers should at least note that this alarming failure rate (Snyder et al. 1989a) was either inflated to begin with, or is at the very least totally irrelevant to today's conditions.	Zach Welch	First note that the point of this paragraph was to mention that at one time nest supports were used to see if researchers/managers could help with nests that were collapsing. We took another look at the publication. We agree that it is somewhat confusing and many factors were involved. We removed the sentence about the 3% and added some other phrases to clarify our text on the results from the study (as well as presenting some different information; see later lines in the paragraph). Since they do not give locations of nests, we can not comment on the reasons for collapse. However, from the review of several studies, it appears that nests in cattail are even more susceptible to collapse during lower water conditions.
23	CH 5; 3163	I would argue they've been suggested by the cited author, but not shown. There is very little data from that time period to say anything was shown definitively. Darby showed a decrease in snail densities from 2003-2004, and suggested it was from high water in the fall of 2003. In fact Darby et al. 2005 actually state in the results "at this point we cannot define a trend based on only two consecutive years of data, and in particular we cannot attribute changes in snail density to environmental conditions." Yet when this report is referred to throughout the review, it IS cited as defining a trend based on environmental conditions. Further, all site comparisons between 03-04 appear to use the highest recorded snail densities from 03, which were in dense panicum at each site. The authors didn't report what habitat they sampled in 04 to compare to 03, whether it was in the same dense panicum, or whether they had different results depending on which habitat was compared. With only 4/5 sites showing density declines from 03-04, all of which occurred in the extreme southern end of 3A, is there enough data to say snail densities declined from high water? Especially when similar high water events occurred just prior to some of the highest kite nesting years ever recorded in 3A (95 high water, 97 kite use)?	Zach Welch	The Darby et al. (2002) paper cited in line 3163 does not deal with the issue of WCA3A depths at all (Darby et al. 2002 reported on data collected on movements in SJM and LKISS). With regards to 3A, one can debate if 4-5 sites are sufficient to say anything. However, seeing the same trend in 4-5 sites that are several kilometers apart and these being associated with relatievely high water conditions is a direct observation and not disputable. Unfortunately, we have very little data on snail densities prior to 2002. The vegetation types sampled between 2003 and 2004 were the same, and also the decline in snails occurred in sites dominated by different vegetation types (i.e, they did not just decline in *Panicum* -dominated sites).

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
24	CH 6; 3366	Only one site was sampled for egg clusters in 2002, as reported in Darby et al. 2005. Also, Darby reported peak egg production in mid March of 2002 (p 38), compared to almost zero production in mid March of 2003... but water levels were LOWER from January through mid-March in 2003, than in 2002. Darby et al. 2005 goes on to mention how much colder 2003-2004 springs were than 2002, though this same paper is repeatedly cited as showing how water levels are the only culprit in reduced egg cluster production. Specifically, it is cited about the importance of 40cm in water depth. Yet the highest egg count Darby recorded for WCA3A (ever?) appear to be from when the water was well above 40cm in depth, in mid March.	Zach Welch	The difference between 2002 and 2003 was that water levels did not fall in 2003 (they stayed up above 40-50 cm), whereas in 2002 they did fall below 40 cm in ~April-May. In 2003, with water levels staying relatively high, few to no eggs were observed. This is accurately described here in our report. By May, temperatures were well above the 21 C threshold discussed in other reports (Stevens et al. 2002, Darby et al. 2005), and there was little difference in 2002 vs 2003. However, despite relatively high snail densities, egg cluster production overall in 2003 was very low compared to 2002. You cannot just look at the graph on eggs to understand these patterns. So it is reasonable to conclude the higher depths did contribute to fewer eggs. Additional relationships were described (and stated here) from Darby et al. (2009) that further support the associations described. Also, more eggs (on a per female basis) were found in more northern sites (shallower depths) at the same time southern sites (deeper depths) were not producing eggs, and these different sites were experiencing the same temperatures. Finally, the decline in snail densities in four sites in 2004 is consistent with low egg production in 2003 that was associated with relatively deep water, especially in the March-June period. Since the high end of what may negatively influence egg production is less clear than the low end (less than 10 cm, snails stop moving), throughout the document we talk about the high end as being estimated somewhere in between 40 and 60 cm. This does not take away from the fact that lower egg production has been observed (even on a per capita basis) to be negatively influenced by relatively high water depths in the spring breeding season.
25	CH 6; 3389	But again, the highest egg cluster count was from when water was >40 cm in depth. Once water decreased from 40 cm, egg production declined at site 10 in 2002.	Zach Welch	The important comparision is 2002 vs 2003 conditions. The reviewer is not pointing out the order of magnitude lower production of eggs in 2003 compared to 2002, and noting that in 2003 depths never fell below 40 cm in April-May. Again, what Darby et al. (2005), and cumulative evidence, are showing is that relatively deeper water was associated with suppressed egg production-- what precisely that depth is should be studied further. Also, we agree (and in many places had already stated) that the upper limit of 40 cm may need to be re-assessed (see August draft report line 4971). The most important message is that relatively high water is associated with fewer eggs produced (total, and on a per female basis). We have modified the text in several places to de-emphasize the 40 cm value, and re-emphasize the point about the negative high water effect. This is a turning point for consideration of effects of hydrology on snails, where so much of the earlier literature focused on negative impacts of dry downs.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
26	CH 6; 3390	If snail densities reflect the previous year's egg production, why weren't there higher snail density estimates in 2005? According to the tables 8-1 and 8-2 (p 234-5), 2004 had way more days between 10-40cm throughout the entire year than 2002 did, so production should've been through the roof. And if the justification is that snails weren't able to recover from the traumatic 2003 high water event in high enough numbers to lay a bunch of eggs in 2004, then why not? For example, according to the tables, 1996 was preceded by very high water years (devastating to snail production according to this logic), and in 1996 there were only 4 sites with 20-116 days of 10-40 cm; very similar to the devastating conditions reported for 2003 when there were 4 sites with 38-101 days of 10-40cm during the spring/summer. And 2003 was preceded by much drier years than 1996 was, so there should've been even more snails, right? Yet snails laid so many eggs in 1996 that 1997 had one of the most productive years ever in terms of kite nesting. 2003 though, somehow had a fantastically different effect and even the great conditions of 2004 couldn't make a blip in the snail recovery. I just don't think we're seeing the big picture here. The conditions of 2003 were simply not catastrophic enough to have had this apparently decade-long effect on snail densities. If they were, then why aren't the far wetter periods from 1993-1997 the real culprit here? Haven't snail kite numbers been declining in 3A since 1998? Additionally, if 10-20cm more water in an area of marsh will dramatically alter snail populations, how do snails lay eggs in lake systems, where it's typically >40cm in depth? Wouldn't this be fairly easy to test in a lab setting? There are other possibilities mentioned elsewhere in this review, like predation effects, parasites... but this 10-40cm depth keeps being cited as definitive, and I think it's far from that.	Zach Welch	The number of eggs produced reflects environmental conditions (which requires further study), but also the number of females available to lay eggs. In 2004 there were very low snail densities in the site reported, and therefore few females to lay eggs to recruit into the population for 2005. This is a depensation effect, and we have added some text to make this more clear (see Chapter 9, since this idea was not originally made in the cited literature on *Pomacea*). There have not been studies to address how long it may take to recover a low snail density population in the WCAs, and we have addressed that in a recommendation in Chapter 11. The idea that "great" conditions did not result in a big increase in snail densities the following year likely reflects this issue of depensation (the current working hypothesis, see background in recommendation 11-3). Also note that reference to 1996-1997 is not quite appropriate, as many kite nests were distributed further north (higher ground elevation). The observations for 2003 were on southern sites in 3A. So even though stages were similar (or higher) in 1995-1998 as they were in 2003, depths were deeper in the south (2003 data) versus the north (where kite nests were in 1990s). We can only report on the data we have, and the association between relatively fewer eggs and deeper water was based on direct observations. Any "hindcasting" back to the 1990s is speculation since we have no data on trends in snail densities during that time. We agree the 10-40 cm depth requires more study/refinement (and stated so in the August report). We also agree there needs to be lab or mesocosm studies on this topic (see recommendation 11-b-10 in August draft).

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
27	CH 6; 3615	It also speaks to the highly variable distribution snails can apparently have within one community. How confident are you then, that sampling for snails outside of the sawgrass/prairie ecotone is effectively sampling the snail community?	Zach Welch	Any throw trap study reflects a snap shot of snail distribution (snails move at rates that easily traverse many habitat types over time). Also, the published studies cited analyzed the effects of plant types on snail densities, and that is how we know there is variability in heterogeneous habitats. As far as confidence in the throw trap sampling, they typically sample 50-100 traps in a site that are randomly distributed throughout the site. "Confidence" is reflected in the statistical results and significant differences reported in the cited studies. The sampling protocol and degree to which throw trap sampling represents a snail density in the sites sampled have been published in several peer-reviewed publications and thoroughly "vetted." Also, the published throw trap sampling often targets certain objectives (e.g., assessing snail densities where kites forage), and in those cases the sampling does not pick up the full range of variability due to vegetation types, because vegetation types where kites do not forage were not sampled.
28	CH 6; 3622	Isn't this opposite of what Bennetts et al. 1988 found, as referred to earlier in this report? Didn't he find snail densities 2-3 times higher in dense panicum than in sparse? This may be incorrect, but it seems like panicum, especially denser panicum, is closer to the sawgrass interface. Again, is it likely there are more snails in the sawgrass/prairie ecotone than is being reported for outside it?	Zach Welch	Bennetts et al. (1988) did not report on specific stem densities or plant species with regards to apple snail density. We assume you mean Bennetts et al. (2006). In Bennetts et al. (2006), they are clear that dense *Panicum* has lower stem densities than dense *Eleocharis* . 'Dense' was a categorical term, and issues with the term were discussed in detail (and related to actual stem densities) in both Bennetts et al. (2006) and Karunaratne et al. (2006). We revised the report to clarify that point. The stem density comparison we referred to on line 3622 was for *Eleocharis* stems only. We also modified the text in chapter 5 to emphasize the visual obstruction (not just stem density). We have also made clarifications related to snail densities.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
29	CH 7; 3899	Suggesting that there's a positive trend between number of kites foraging and snail density, and then immediately following with explanations about why that trend shouldn't be relied on, seems counterintuitive. Authors argue that only 1 kite was in a high density area, whereas 4 were in low density areas. Perhaps snail availability is more important than density in terms of kite habitat selection. However, it's perfectly logical that more kites forage where snail availability is higher, so it seems like a good surrogate for estimating snail availability, especially if sample size and effort is increased.	Zach Welch	We see no problem here. There is an overall trend that was supported statiistically. Here we provide some cautionary statements (which the reviewer advocates in many other places in the report), that since kites explore, we may encounter them at times in low snail density sites. Overall, however, reports of more kites foraging for and catching snails at higher snail density sites makes sense. Finally, it is not just the trend, it is the actual snail density that is of interest. Understanding what kites respond to helps us assess and/or manage for areas in support of snails. If kites are not foraging in an area, is it because there are too few snails? Darby et al. (2006) is one paper that gets at that questiion -- how many snails are enough? The reviewer has made it clear that in his opinion snail density data do not provide critical information (see Z. Welch comments on recommendations related to snail density), but others in the management and scientific community do not hold this view (see review comments and recommendation chapters).
30	CH 8; 4188	Again, this might be a poor predictor, at least with the data reviewed by this report.	Zach Welch	Part of the value of a model is to explore relationships that can then be validated with existing data, or with data yet to be collected. Also, the reviewer seems to be focused on the 10-40 cm data; however, on line 4188 the depth effect includes depths of zero (dry downs) that have a clear negative impact on egg-laying. As to a "high" water effect, this will continue to be explored. No results of the model (or its validation) are reported here, so any assessment of whether depths are a poor predictor is invalid.
31	CH 8; 4308	Again, if 2003 was so bad for snails, how were 1994 and 1995, two consecutive years, not? Highest kite nesting in 1997-98, recall.	Zach Welch	See response to comment #26 above. Also see publications by Bennetts regarding high water influences on where kites nested (they shifted north, to relatively shallower portions of WCA3A) (see Chapter 5).
32	CH 9; 4321	I think the conclusions were presented with bias in some cases. The reviewers cautioned readers about the reliability of results in several instances, most notably with Martin et al. 2008, and then neglected to caution them in cases where the original authors (Darby et al. 2005) even expressed concern with interpreting too much from the limited data.	Zach Welch	We do not agree, noting that we also made cautionary statements about how definite the 10-40 cm depth was (which we have emphasized even more in the final report), and regarding Darby et al. (2006). Cautionary statements regarding Martin et al. (2008) came from the fact that some findings were contradictory to some earlier publications. Also, see the Bennetts comment matrix, in which he supports caution being taken for some of the Martin et al. conclusions. Further, other reviewers commented that pointing out discrepancies or areas of disagreement was useful to the reader. Also see Chapter 9.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
33	CH 9; 4340	Generally, I wouldn't expect many of a particular species' publications be dedicated to prey availability. There are tons of other stuff to publish about the species as well. What percentage of apple snail literature has to do with their food? Or kite demography? It makes sense that some of the publications should overlap, but not a high percentage. Besides, the 5% that you mentioned basically cover the prey availability/density and how it relates to demography. I think the biggest need is for more information about how to grow snails. The real gap is in the snail literature... after 30+ yrs of snail studies, we still don't have good data about what maximizes snail production in the Everglades.	Zach Welch	We fully stand behind the text as was written. We believe that for a species that eats nearly exclusively one type of food, information on that food is extremely important (its availability, its abundance, and what affects it). Most species do not have such a narrow prey base. Regarding your last point, more would be known about the Florida apple snail, but few RFPs have emerged to address these questions. We have made recommendations for such research in Chapter 11, and agree it would be important. Finally, prior to 2000, there was no concern expressed for snails except for the impacts of drying events. In the extant flooded wetlands used by kites, food did not appear to be an issue. The idea that snail densities could decline in critical wetlands like WCA3A or WCA2B to levels that would impact kite foraging has only recently (last 8 years) emerged. Also see response to comment #29 above.
34	CH 9; 4349	I think whether Darby's methods of estimating snail density are cost-effective or not, are really not something that should be commented on in this review. Cost-effective is a subjective term, and likely will vary considerably depending on who you ask.	Zach Welch	We do not agree with the comment. As this reviewer states in comment #33, there is a significant information gap in the snail literature. There has been an impression, for years, that snail sampling is just too difficult and costly (see Valentine-Darby et al. 2008). Cost-effective approaches (which should still be developed further) give the management community a realistic chance of supporting critical information needs on apple snails. We have added a statement in the revised Chapter 9 to reflect the reviewer's views on snail sampling (which also applies to comment #35 below). Also, other researchers and managers sample for snails and other aquatic species using throw traps; these are not just Darby's methods.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
35	CH 9; 4352	Prey density is irrelevant, except as how it relates to availability to kites. When kites leave a wetland, it's pretty obvious there's nothing to eat there. Darby has suggested the trend numerous times for 3A during poor nesting years (Darby et al. 2005, 2009). So all the papers and reports that relate kite movement to habitat conditions, prey availability is inherently part of that. Most papers deal with habitat and hydrological changes, which are a step beyond prey density. They're trying to explain or relate trends in habitat and water to presumed low prey availability. If there are no kites nesting in 3A, chances are there is very low snail availability. Again, the gap in information isn't in explaining what causes or is correlated to kite movements, but in explaining why snails do not seem to be recovering in 3A. At least in my opinion.	Zach Welch	We do not agree. Prey availability is largely driven by snail abundance. Kites do not forage in habitats where they cannot access snails, so in that case we agree that prey density is not directly important to kites. However, in the many areas where the habitat structure is conducive to kite foraging, prey density is critical. Without snail sampling, how do you know if there are insufficient prey numbers, or some other problem -- the effects of hydrology or vegetation are irrelevant if there are no snails in the area. Hydrology and habitat are not "beyond" prey density. The habitat structure and hydrology in WCA3A have recently been suitable for kite foraging (i.e., there are 1000s of hectares of low to moderate stem density prairie with standing water). How do you know there are no snails there without sampling for them? If kites are not using an area and management wants to improve conditions for kites, how do managers know if it is a snail abundance issue or some other issue. Also see our responses to comment #29 and # 51. Also, a few recent publications by Darby et al. have focused on what constitutes a sufficient forage base for kites, and this has used snail density data.
36	CH 9; 4356	This is a pretty serious statement, especially for an unbiased review paper. What incorrect conclusions and by who? Such accusations should be spelled out and well-defended.	Zach Welch	This statement is supported by the literature cited in Chapters 4 and 6. This is not biased. We modified the sentence to put emphasis on the old assumptions about dry down tolerance. It is a fact that apple snails have been directly observed to tolerate drying events, so that earlier assumptions that dry downs kill snails were incorrect. It is logical to say that 15-30 years ago managers and scientists had incorrect conclusions about dry down impacts on snails and kites, because we now know that snails can tolerate dry downs for weeks to months at a time. Therefore, the fact that kites do not return to an area, for example, after a drying event, cannot be assumed to be low prey availability. Do dry downs potentially influence snails -- of course, depending on duration, timing, etc. (see Darby et al. 2008 as cited in chapters 4 and 6).
37	CH 9; 4360	In other words, we really don't have a good idea about the population total or trends over that time, because the count methods were unreliable.	Zach Welch	We do not totally agree with the reviewer's statement. To address it, we added a sentence to the text noting the Bennetts et al. (1999a) study, which estimated the population change over the period while accounting for some of the confounding factors (e.g., differences in observers, effort).

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
38	CH 9; 4387	I'm confused by this paragraph, particularly with the last few sentences. Okeechobee IS a critical part of the wetland network. We suspect snail availability was low there for many years, since no kites nested there. Why do we need an increased effort to distinguish snail kite foraging habitat from snail density? What does that mean? We know snail density can be low in what looks like good foraging plant communities. Why do we need to revisit that or spend more time researching it? I don't understand the arguments for increased snail density work as relates to connectivity of the network. We know that if snails aren't available in parts of the network, particularly an important central hub like Okeechobee, that it's bad for connectivity.	Zach Welch	Part of this confusion arises from the Martin et al. papers not distinguishing between snail density and hydrologic and/or plant community metrics. This paragraph is stating that the prey density itself (not neccessarily the water depths or habitat types found in a particular year) is likely driving some of the kite use patterns reported. In other words, you can have appropriate depths and vegetation to support kite foraging, but the snail density itself may be limiting (e.g., what we see in WCA3A). Just because kites are not using an area does not *necessarily* mean there are no snails (there are not nearly enough data to make that assertion, because there are so few data on snail density and/or availability in relation to wetland occupancy and/or movements by snail kites). What if kites had abandoned a wetland and do not return simply because they are currently finding enough food elsewhere? Finally, in this paragraph we are agreeing with Martin et al., as supported by independent snail density sampling. As to the value of snail density data, see responses to earlier comments, and support for such efforts by several biologists representing other agencies.
39	CH 9; 4390	What do snail densities have to do with how isolated a wetland is, unless you're looking at snail availability (connectivity) in peripheral wetlands between the major regions? Why did they need to look at snail densities?	Zach Welch	See response to comment #38 above. Also, if managers are being told that an area has experienced "habitat degradation", do they need to manage for the plant community, target different depths to support kite foraging or nesting, or are there just no snails? How do you know without snail data?
40	CH 9; 4414	Or just low nest success when predation or low water obviously isn't the issue. What does it matter if we find out there's 0.2 or 0.35 snails where kites are foraging? What would we do differently as managers? We'd already be managing for high snail densities. In fact we are currently, but of course we have no idea how to do that.	Zach Welch	But how do we know for sure whether it is an issue of low food or predation on nests? Causes of nest failure often are not obvious or definitive. If snail densities in an area are low, then we can make recommdations to managers as to how to help the population recover. As to the last sentence, see our response to comment #33, and note that agencies are not posting RFPs to support such research, at least as far as we know.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
41	CH 9; 4446	Which Bennetts suggested was because the snail population doesn't recover fully for years either. Just because snails can pop out of the soil and start laying after a dry down doesn't mean it won't have a negative effect on the population. A dry-down that had no direct effect on either snail survival or reproduction would obviously have no direct effect on kite use the following year, either. So I don't think they're responding on different temporal scales to dry downs, unless plant communities changed enough to alter the snail avialability after the dry down.	Zach Welch	We did not say that there is no negative effect on the snails. The point being made is that snails can recover to some degree immediately after flooding after a dry down, whereas kites have already abandoned the area and make take years to return even though the snails are still there. It is not so obvious about any lag effect on kites returning to an area in relation to snail density -- there are little or no data to document this. Most of Bennetts' work, especially conclusions about why there is a lag phase prior to kites returning to an area, were made prior to research showing snails tolerate some drying events. We are stating here that depending on the details of the dry down, kites will definitely leave (that is well supported by literature going back to the 1980s), but we also know that snails can survive and recover to lay eggs.
42	CH 9; 4450	The reviewers argue in several places in this report against Martin et al's (2008) use of more recent hydrologic period than earlier Bennetts studies, and yet point out here (correctly) that recent past hydrologic conditions are likely important. For example, after 20 years, a wetland has likely changed signficantly and what happened back then hydrologically would likely have much different effects if it happened now. I would ask the reviewers to refer to the comment here when trying to compare effects from stage levels across multi-decadal time scales, as discussed ad nauseum in Appendix C.	Zach Welch	It is obvious that there is disagreement as to the value of stage and drought score value (DSV). However, we do not see a problem with advocating for more spatially explicit depth data. This has been advocated for wood storks, for example (see Beerens et al. 2011; PCD also had personal communications with Dale Gawlik and others participating in the federally-hosted, periodic Multi-Species meetings). Also, the point of putting something in an appendix is to not belabor a point in the main body of the text, and to leave it to the reader to decide how interested they are in the topic. The developer of the DSV (and similar hydrologic indices) agreed with our characterization of the discrepancy (see comments by Bennetts). Regarding significant changes to wetland plant communities, we have addressed this in Chapters 5 and 9, citing Zwieg and Kitchens (2008) and others (also see Appendix D). However, how these changes in vegetation might have influenced hydrology (as assessed by stage) as it relates to snail kite ecology has not been quantified in the literature.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
43	CH 9; 4466	Yes, depending on the dry down. That's why there's a variable lag period for kite return... it depends on the dry down, and how much it affected snail availability.	Zach Welch	The mechanism has not been determined because there is so little data on snail densities for these dry down scenarios. The failure of kites to return to an area could be a function of their finding other areas to nest and forage, so they do not return for a year or years later when they return to explore (and find there are snails available). We do not know without the snail density data to show that snails were or were not severely impacted by the dry down. Also, note that snail density could be influenced indirectly (even under a "mild" drying event), if a significant number of probing predators arrive in the dry down area (see Darby et al. 2003). The idea that a lag time exists and may be proportional to the negative impacts of a dry down has been presented in the past, but has little data to support it. We are not aware of any data that show kites fail to return to an area because a dry down reduced a snail population.
44	CH 9; 4468	I don't see why monitoring egg clusters can't show trends in snail abundance. Sure, there can be few clusters and many snails, but the following year there would have to be few clusters because of few snails, right? Either way you find out there's not many snails reproducing, either because there aren't many snails or because the conditions aren't conducive to egg laying. Seems a lot easier.	Zach Welch	See line 3854 (August draft). Egg cluster counts explained only 23% of the variation in snail density. More data has been collected on this topic (PCD), but a meta-analysis on the several different data sets has not yet been completed. It is possible that under certain conditions (e.g., at certain depths that do not appear to negatively impact egg production) egg counts might provide some utility. We do not agree that you can predict whether snail availability in an area will be sufficient to support kites (i.e., actual snail density matters). So if there are few eggs produced per female, but the area has very high snail densities, it could be that enough young are produced to have enough snails availabile to kites the next year (even if the trend is a significant deline, e.g., from 1.5 snails per m2 down to 0.3 snails per m2). Perhaps egg counts have value in understanding snail or kite trends, but to date the literature does not support this assertion.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
45	CH 9; 4483	Again, I think the reviewers have misunderstood Martin et al (2008) findings. The researchers included 1999, 2000, 2002, and 2004 as moderate droughts, and 2001 as a more severe drought. That's 5 in 7 years, and the study suggested that those conditions reduced the population growth rate from what it was in the 1 in 7 year moderate drought period. The Bennetts study simply suggested that the areas kites nested in during a very short period of study (86-87) in 3A appeared to have gone dry every 2-4 years over the 19 yr period prior, but mentioned nothing about moderate droughts. Since that study, of course, water levels changed significantly in 3A. As Martin suggested, high water outside of the breeding season likely degraded the habitats as well, and suggested moderate droughts combined with habitat degradation was lowering population growth rates. Cattau (year?) later said amplitude was bad for kites in the area as well, which supports Martin's findings. Additionally, Bennetts didn't look at moderate drying event frequency, which Martin argued would allow for kites to successfully breed but which would lower juvenile survival afterward. At least a more extreme drought would simply cause kites to leave the area and possibly find somewhere else to breed. Martin also mentions several times in the discussion about the dangers of holding water too high or eliminating droughts, and they even cite Bennetts for that. This review consistently interprets Martin et als. (2008) findings as advocating for higher water and longer hydroperiods in all wetlands managed for kites and that's simply not the case.	Zach Welch	What Martin et al. (2008) considers as "moderate drying" is a relative term based on their period of study. How is it that moderate drying events appear to be a problem in their study, but this contradicts Bennetts 1998 (see conclusions of the Martin et al. paper)? And how do we interpret what a moderate drying event means, when Bennetts and Kitchens (1997) found such hydrologic conditions were non-drought? Could it be that prey density or other habitat conditions were quite different, and this had an overriding effect on the interpretations of Bennetts vs. Martin? Martin et al. (2008) talks about habitat degredation, but what aspects of this degradation should managers address? Could it be that moderate drought conditions (like in 2001-2002) were good for snail production (which they were based on snail densities in southern WCA3A)? Moderate drying events may be essential for long-term maintenance of the kite network of habitats, but in our reading of Martin et al. (2008), the emphasis is on "moderate drying events....greater threat to kites than lack of droughts." We agree that Martin et al. (2008) effectively points out the issues of habitat degradation versus drying (i.e., wetlands can alternatively be too dry or water levels too high), and that there may be appropriate middle ground to support kites. However, they do not explain why Bennetts (1998) did not come up with the same conclusions, which likely reflects the conditions during their respective periods of study. To address this comment, we removed the discussion of discrepancies in Chapter 5 and presented some of these ideas in Chapter 9. Also see our response to comment #9. What we emphasize is that there are differences of scientific interpretation here (also see review comments by Bennetts in this report), and this suggests we need additional analyses, including the influence of prey availability, on how kites respond to fluctuating hydrologic conditions. Also note that we had already presented the information from Cattau et al. (2008) on amplitude in the August draft (Chapter 5).
46	CH 10; 4690	I didn't think the purpose of this review was to endorse any particular findings	Zach Welch	We do not see any problem here. We are saying that we are NOT endorsing any findings here. No change was made to the text based on this comment.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
47	CH 10; 4768	You can't refer to spatially explicit water levels everytime you're talking about water depths. People use stage data because you can relate it to whatever location on the landscape you want. If someone needs to know how many cm of water that is at a particular location, they can measure that themselves. You can also use statistics of stage data to define certain water levels and their relation to seasonal, annual patterns, etc. This review repeatedly calls for using depths at specific locations, which is a very small scale, incomparable measurement that wouldn't make any sense when talking about landscapes. "Kites respond to depths, not stage" - What is stage a measure of? Water depth at a particular spot. This is a nonsensical, and unfortunately often recurring, argument.	Zach Welch	First, the point is to use this information when possible. Many times using stage data makes sense and it is all that is available. However, in other cases having specific water depths is much more meaningful and more work is leaning in that direction (EDEN data). Several reviewers of this report have supported this recommendation. We do not agree that it is nonsensical. With regards to depth information available at large scales relavent to snail kites, see EDEN. In addition, there is a history of using certain stage data, e.g., 3A-Avg, that do not accurately reflect wetland conditions in the portions of wetland units used by kites. Finally, stage is a measure of water level elevation above mean sea level, and without topographic data (ground elevation) does not indicate depth. Snail and kite (and kite nest) location data are recorded during sampling and/or monitoring, so depths at specific locations (at least in the case of EDEN data) are available. Perhaps it is challenging to make the transition away from stage and more towards depth estimates, but we certainly do not agree this effort is nonsensical. Also see response to comment #42.
48	CH 10; 4848	There's already published research on kite movement between and within regions and units. Not sure why we would need new studies on kite movements, except to see if they're traveling farther to feed or concentrating nesting in new areas.	Zach Welch	This recommendation was not calling for new studies; rather it called for analysis or reanalysis of existing/new data on a wetland unit basis. Also see comments on this same issue by R. Bennetts (e.g., R. Bennetts comment #26, #9). We have deleted this recommendation and make some of these points now in Chapter 9 of the document since this appears to be an area of disagreement. The idea of a meta-analysis that might include available snail density data, as well as the EDEN data, has been brought up by those conducting kite research (Rob Fletcher, pers.comm.)
49	CH 10; 4864	There's already a group of birdwatchers throughout the state that consistently report kite sightings to researchers. New areas are surveyed every year from these sightings.	Zach Welch	Acknowledged. We had not come across this information in the annual monitoring reports. We have added a note based on the comment in the existing recommendation. We believe it would be beneficial to encourage more participation from birders/ecologists throughout the state. We also added a note from another reviewer in this regard (M. Cook, comment #11).

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
50	CH 10; 4887	This is not an issue. Nest detection and proportion of juveniles banded has never been higher. Birds and nests are much easier to find when they're all in the KCOL. Cattau was referring to the fact that for some number of years, juveniles (banded) were failing to recruit into the population in high enough numbers, and banded adults were dying. So the overall proportion of banded individuals was going down, but I doubt that's the case now that juvenile survival in the KCOL has picked up and older, unbanded birds are dying off. If anything, the push would be for more adults to be banded, but I don't think this is an issue currently.		Kite nests may currently be most abundant on lakes, but that does not mean it will remain that way. The number of nests and fledged young is critical to sustaining (or growing) the kite population, and nest detection rates are not well studied (see Martin et al. 2007). It would be beneficial to have a way to quantify nest detection, especially when birds are using habitats in which it is inherently more difficult to find nests (when they are not concentrated on the lakes, e.g., in WCAs, Grassy Waters). Cattau et al. (2009) talked about the importance of having a sufficient number of banded birds. In addition, PCD inquired about this issue recently, and Cattau (pers. comm.) responded that a limited effort to quantify nest detection was made (~2006 or 2007), but those data have not been analyzed or reported. We left the recommendation in the report, but can modify it in future revisions as more detailed information is available.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
51	CH 10; 4913	This statement is incorrect. They appear to give a rough estimate of snail density within areas that kites are already using. Snail densities could be very high and completely unavailable to kites. To date, studies linking snail densities and kite foraging only looked in kite foraging areas. They also showed that kite foraging rates were a great way to estimate snail availability, which includes an estimate of abundance inherently. Without looking at measures of availability, I would argue snail density monitoring isn't necessary, except to answer specific questions about snail response to various stimuli. I would argue plenty of information could be garnered from simply doing egg cluster counts. If there are no eggs, there are either no snails or conditions are bad for laying. Either way, the next year snail counts should be low, right? That would give managers plenty of information regarding whether snail abundance seems to have declined or increased over a given time period.	Zach Welch	This first sentence (about snail densities and habitat quality for kites) is not needed in the background of this recommendation so we have deleted it. Also note cumulative evidence for this idea in Chapter 7. Others support this recommendation, and one researcher (C Ruehl) stated it was one of the most critical recommendations. The fact that Darby et al. publications sample snails where kites forage (but not in habitats where kites have long been known not to forage, e.g. , dense cattail), should not be a surprise. However, given this comment, we clarify this statement on line 4913 to say that we mean obtaining snail densities for those plant community types (e.g., low to moderate stem density emergent marsh) known to support kite foraging. This is not to say that getting snail density estimates in other habitats (e.g., dense sawgrass) would not be valuable for reasons other than direct ties to snail kites. Also, snail availability is influenced by many things, and if you do not know the density, you cannot say if snail availabiltiy is influenced by the plant community structure, temperature, turbidity, etc. Yes, density is part of availability, and for that reason, especially given the few studies that link snail density to kite movements and demography, several managers, reviewers of this document, and other review documents (e.g., SEI 2007) continue to recommend snail density data be collected. Also, if we only assess snail availability by observing kites, we can say nothing about snail availability if kites are currently not using an area. To date there has never been an assessment of how kites shift their occupancy of wetlands throughout the network in relation to the food supply because relatively little data exists on the snails themselves (relatively little in terms of the spatial scale of the kite network of habitats). As to egg cluster counts, if there are no eggs and we do not have snail density data, then how do we know if the conditions are poor for egg-laying, or if there are no or few snails? The reviewer argues in several places that we do not have enough data to show what hydrologic (or other) conditions influence snail egg numbers; consequently, we need more data on snails and eggs in order to understand the conditions that best support egg production. We agree that documenting snail egg production might tell us if the snail population were going to increase or decrease in the future, but that still does not provide information on the actual snail density (a major component of prey availability) to snail kites. Finally, what kind of egg numbers in an area are needed to maintain or grow a snail population? What is a "low" egg count?
52	CH 10; 4959	So if low snail densities result in fewer kites foraging, longer foraging bouts between captures, and decreases in foraging success... why not just measure any of those indices instead? Aren't those the indices we're trying to measure anyway? Why do we need to collect so much information as to know whether there are 0.2 or less snails per square meter? Why not just watch the birds? Snail density studies should focus on specific questions related to snail response to various stimuli, in my opinion.	Zach Welch	Because if there are no kites present, we cannot collect any foraging data. If there are no kites present, we cannot conclude that there are no snails. Snail density- kite relationships demonstrate that too few snails or low snail densities will result in few or no kites, or longer foraging bouts, but the converse may not be true. Kites may be absent from an area but snails could exist. If that is the case, perhaps essential components in the habitat are missing or the habitat is otherwise unsuitable (perches, the vegetation is too dense for foraging, etc.). If kites abandon an area, then data on prey avaiabiltiy and the habitat would be a foundation upon which to make management decisions, either to increase snail abundance or mange the plant communities or depths to increase availbility of snails. We agree that studies of how snails respond to their environments are also important, but that also requires snail sampling.

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Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
53	CH 10; 4971	Exactly. What's needed are additional studies to determine how to maximize snail production.	Zach Welch	We agree. We have also modified this recommendation to put more emphasis on the need for more data on what conditions to target (we had already stated that on L 4971, but added a new, separate sentence).
54	CH 10; 4977	But Darby et al. 2005 measured the highest number of egg clusters on a transect in 2002 when water depths were ABOVE 40 cm. Once the water dropped below, the cluster counts decreased as well.	Zach Welch	Here we say ~40-50 cm. Darby et al. (2005) used a 40 cm line as a reference point. The 40-50 cm range accomodates some deviation from that very specific 40 cm depth, acknowledging we should not stick too closely to a single number. We have clearly stated that more work needs to be done to identify these depth ranges that support snail egg laying (see recommendation D-4 in the August draft). Relatively warmer temperatures may have explained the earlier peak. However, also look at year 2003, where peak producion (and overall higher eggs) occurred in Site 11 (higher ground elevation compared to Site 10), whereas production at the same time in Site 10 was much lower. With regards to hydrololgy, depths dropped below 40 cm in April and May in 2002 in southern 3A, whereas they never dropped below 40 cm in 2003. Again, the drop after a peak reproduction has been associated with adult-sized snails dying off (see Darby et al. 2008). Here (line 4977) we also reference Darby et al. (2009) and refer to per capita egg cluster production being greatest in depths between 10 and 40 cm. In other words, just looking at Darby et al. (2005) does not present the full story with available data to date (and more needs to be collected and analyzed).

External Review Comments: Phase 2
Z. Welch Continued

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
55	CH 10; 5005	Unsubstantiated. Kitchens et al. trapped apple snails in crayfish traps in the middle of high density, monoculture pickerel stands prior to the 2004 muck removal project on Lake Toho.	Zach Welch	This work was based on the findings of Darby (2006), which the text now clearly states, and was based on many more samples than collected by Kitchens et al. These are direct observations based on hundreds of samples taken in pickerelweed stands. We reviewed "Monitoring Floral and Faunal Succession Following Alternative Habitat Restoration Techniques in a Large Central Florida Lake", Kitchens et al. (2008), and found no specific information on where apple snails were captured. No information was provided on plant community types (pickerelweed) in regard to the capture of snails. Therefore, we added a statement to our report based on the comment using a pers. comm. and mentioning the report. PCD recalls discussing the snail catch rates on a site visit with the Coop Unit sampling team on LTOHO, and in sites with monocultural dense vegetation, the numbers of snails captured were very low. This is consistent with Darby et al. finding no snails in their sampling. Finding zero snails never guarantees there are absolutely zero snails in an area, but it certainly indicates very low densities (too low to be of value to kites as prey). These data support our point that monoculture pickerelweed do not support populations of snails that can support kites. We slightly modified the sentence to clarify this point.
56	CH 10; 5013	This is un-natural and highly unlikely to occur. Any managed drawdown is going to mimick natural drought patterns, where water levels begin falling in the fall and continue until the wet season. That may result in lower snail recruitment during the spring, but you can't realistically dry a system out during the rainy season. Besides, this review has repeatedly stated how tolerant snails are to severe droughts, and how they can simply lay eggs as soon as the drought ends. I would argue that the biggest effect will be the unnatural ascension rates that would follow a managed drawdown, as people want their waterbodies returned to normal levels ASAP. That could likely curb fall egg production as well, rendering the whole year less productive.	Zach Welch	See Darby et al. (2004). The drawdown on LKISS eliminated the peak period of egg production, and in the following year the snail population declined by > 80% in study sites sampled. The 1995-1996 drawdown would have resulted in a dry littoral zone even earlier than planned (the target was late February), but there were several rain events during the dry season (typically uncommon). Regardless, as to what is "natural" is debatable since there are constraints on water levels as a result of surrounding development and agricultural interests. Finally, rapid ascension rates may flood some egg cluster production, but that would be a temporary impact as snails would continue to climb above the water surface to deposit more eggs. This assumes the water levels do not rise so high (deep) as to have a negative effect, for example submerging otherwise emergent vegetation (an effect of the depth itself, not change in depths). We realize there are logistical challenges in modifying the way these drawdowns and muck removal projects are conducted, but in the past organizations have questioned the process and requested alternative strategies be considered to ameliorate negative impacts.

External Review Comments: Phase 2
Z. Welch Continued

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
57	CH 11: 5186	funding sources are fairly limited, so I can't see why expensive telemetry studies about movements would be re-done at this point. There seems to be a lot of concern about peripheral habitat use throughout this review, but unless we're trying to find 1-2 more hotspots to acquire land for conservation, I don't see what satellite or radio data would provide other than anecdotal info about how far or not far birds may go. There are more data collected about snail kites than most other species, and yet this review suggests we go back and re-do earlier studies. I would argue we focus our collective funding and research energies on topics with immediate returns, and areas with the largest information gaps. How kites move between landscapes does not fall under that category in my opinion.	Zach Welch	The reviewer misinterpreted the text here and in other recommendations- we did not suggest throughout the report studies be redone; in a few places we suggested data be analyzed in a different way. Regarding this recommendation, we do recommend additional/ongoing (as some satellite telemetry work is currently being conducted) studies. Satellite telemetry work by ARCI finds that kites are being sighted in other areas outside of the main areas. The SEI (2007) avian and wetlands ecology panel report also made a similar recommendation. R. Bennetts (the only P.I. to date to conduct a large-scale telemetry study) points out that we still lack information on kite movements during extenstive regional droughts because his study (1990s) was during a relatively wet period, and no large scale telemetry study has been done on kites since. We understand funding sources are limited, but that can be said of any study recommended in this document. Also, if these data were collected in conjunction with prey availability data (including snail densities), we could fill critical information gaps that still exist with regards to kite demography and movement as influenced by spatial and temporal variation in prey availability and other habitat conditions.
58	CH 11; 5243	Why? Stage IS a measure of water depth. What good would this do? Studies linking kite movement to stage data would say the same thing as those using water depth, just on a different y axis.	Zach Welch	Not true, since deviations from stage could mean a dry down in some wetlands (or portions of wetlands) but still flooded marshes elsewhere. So for example, where Martin et al. (2006) report a DSV of -1.9 in WCA3A in 2006, we found (and EDEN also reports) ~30 cm of water in southern WCA3A sites and -11 cm in sites ~15 km north of there. Of course changes in stage reflect proportional changes in depths, but absolute depth, which is critical ecologically, cannot be derived from stage data only. In this final report, we recommend emphasis on depths in recommendation D-6 (was B-4). We have deleted this recommendation here (11-A-7) since emphasis on depths can be incorporated into future monitoring and research on snails and kites.

External Review Comments: Phase 2
Z. Welch Continued

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
59	CH 11; 5318	Again, 10-40cm? At least specify that this is related to 3A only, and that there is very little data to support it, some of which is contradictory. Certainly snails lay eggs in deeper than 40 cm in lake littoral habitats, for example.	Zach Welch	There is no apriori reason to believe that snails in other WCAs or lakes would respond any differently to depths than the way the snails do in WCA3A. The data reported to date are not contradictory, and although some analyses have yet to be done, simililar trends on negative influences of relatively deep water have been shown outside WCA3A. Snails also produce some eggs in > 60 cm depths in WCA3A, but the numbers of eggs produced (especially when expressed on a per snail basis) are much lower (and in several instances zero) than those observed in depths between approximately 10 on the low end and 40-60 cm on the higher end. Here, we have generalized the recommendation to say that influences of water depth should be examined.
60	CH 11; 5352	I don't see why this is important. What are we going to do, change the water chemistry in an area to promote snail growth? Unless you're looking at specific effects from nutrients or something, but that'd be hard to tease apart from its indirect effects on habitat. I think studying how to promote reproduction is more important. What triggers males to find females? Do females emit phermones to initiate, and if so, what's that trigger? Maybe low egg production has to do with missed mating opportunities, and not necessarily just that females didn't want to lay eggs. What triggers the females to lay eggs, anyway? If we know there's going to be a cold winter, do we keep water high (buffer the temps) or low (warm up faster)?	Zach Welch	Influences of water chemistry (including phosphates, a major topic in Everglades restoration) can be studied in laboratory and mesocosm studies, therefore avoiding confounding effects of changes in habitat structure. Two reviewers of earlier drafts supported this recommendation and contributed important ideas to the background. As far as management, addressing chemical runoff and nutrient enrichment is addressed by management (at least by some agencies). Finally, basic information on how snails respond to their environment helps us understand limiting factors for snail population growth and densities, and therefore our understanding of which habitat types (or wetland areas) should receive greater (or lesser) emphasis as far as management to support kites and snails. [Regarding the questions, see Valentine-Darby et al. (2011) for some info on how various snails use chemicals to find mates].

External Review Comments: Phase 2
Z. Welch Continued

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
61	Appen-dix C	This whole appendix is semantics and used as another outlet to criticize the Martin et al 2008 study, apparently because the reviewers disagree with the term "drought" as used there. It's semantics. Martin called every year either wet, moderately dry, or extremely dry. Notice that none were average, or moderately wet, or extremely wet. He could've called them A B and C. The fact is, he used robust statistical techniques to show that the spring/summer water levels from 1999-2007 were more harmful to kite population growth than those from 1992-1998, which is extremely obvious even looking at nest numbers and population estimates. At no point in the study did Martin et al. suggest that the "moderate" or "extreme" droughts were relative to the levels experienced prior to 1992, or make any assumptions about what those levels would mean in that era. As for DSV's, they're a statistically valid method of quantifying water DEPTHS as they relate to other depths throughout a given period, and are an accepted method of defining low water periods in the scientific literature. Water stage IS water depth, at a particular location. If a reader wants water depth at another location, it's up to them to find that out based on ground elevation relative to the reported stage data. Similarly, if managers want to know how certain years classified as "drought" in a certain paper or by a certain method stack up to previous years, they can simply look at a graph. Of course flora and fauna respond to water depths, but they vary across the entire 3A landscape. That's why people use stage data, so everyone can all talk about water depth at one standardized location. Everyone knows that at a certain stage level, some parts of 3A would be wetter and others would be drier. While having a tool like EDEN is nice to know what the water depths are across the landscape at any given stage, it doesn't substitute for relating that stage data to previous years. Martin et al's drought definitions were different from Bennetts because he used a more recent period of record to define them. That's highly appropriate since habitats change over time, and exposing a community in one decade to the conditions it may have experienced 2 decades ago will likely have a much different effect, especially if conditions have been so variable over time. I recommend this whole appendix, and any of the reviewer's apparent issues with using "drought", stage, or depth be cut from the report. As the reviewer suggests, it's all semantics... so why is it even discussed?	Zach Welch	We do not agree. We point specifically to quantified hydrologic conditions for which there is disagreement in the literature and among the reviewers of this document. We do agree that within a wetland you can use stage data to look at trends (i.e., lower water stages correspond to lower depths), but across the landscape and especially between wetlands this is simply not true. Some of these points by the reviewer, and our response to them, have been made previously (see comments and responses #14, 42, 58).

External Review Comments: Phase 2
Z. Welch Continued

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
62	App. C; 6462	And yet those same wetter years appeared to be great for snail populations in the 90's, since 3A supported hundreds of kite nests during that period. This review seems a bit overconfident in what we know about snails.	Zach Welch	A direct association between relatively deep water and relatively low egg production (especially per capita production) has been made, and no one else has reported that egg production is higher in relatively deep (say above 60 cm) vs. shallow (40 cm or below) water. Also, in those wetter years the reviewer refers to, many kite nests were found further north in WCA3A at higher ground elevations (also see comments 26 and 31 and responses). Throughout the document we have acknowledged less certainty on the upper end depths that appear to influence snail oviposition.
63	App. C; 6463	3A HAS had many more years like 2001 and/or 2002. Look at 2004, 2007, 2009, 2011... and yet Darby still found very low snail densities in 2012. Why does this argument keep recurring throughout the document, when it obviously has some serious flaws? How long can we argue that the low snail densities are from 2003, and even though we've had tons of presumably great years since then, they haven't recovered just because there are too few to repopulate quickly? Isn't it possible there are multiple factors, several perhaps undiscovered, at play here?	Zach Welch	The fact is there have been low snail densities since 2004 (not 2003, snail densities were relatively high in the southern end of WCA3A). And correct, they have not recovered, which may reflect a very low population that is in a lag phase of a population growth curve. Also see response to comment #26 above. There have not been any RFPs to address this issue of how to best recover a snail population, but we do make this recommendation in Chapter 11. Also, at no point in the literature is there a report that only hydrology influences apple snail distribution and abundance. A comprehensive study to assess the relative contribution of a variety of factors would be of great value to managers and others concerned with kite issues. Also see response to the next comment.

External Review Comments: Phase 2
Z. Welch Continued

Com-ment #	Sect. Ref.	Comment	Review-er	Pomacea Project Response
64	App. C; 6473	This is a very interesting statement, because throughout this review, the authors consistently use very limited data from very few sites to characterize 3A. And yet here you caution readers about Martin et al. (2008) use of a single DSV to "characterize an entire wetland, especially one as large as 3A, and using these values in a quantitative analysis should be interpreted in a very narrow context". What about using those values in qualitative contexts, as is cited throughout this report? A DSV for a single wetland is based on a water depth at a specific location, which has a pretty high correlation with water depths throughout the entire wetland unit. Much more so than egg cluster counts at a single location in southern 3A, though this review repeatedly cites Darby et al. 2005 as definitively showing that 2003 is to blame for low snail densities there.	Zach Welch	The reviewer has stated, and we agree, that a limited amount of data on snails has been a problem. As far as some of these potential effects, they have emerged relatively recently. The fact that low snail densities in WCA3A have not recovered yet raised the issue of a possible depensation effect (see above #63), and that has come to light just in the last few years. There have been no other observations of negative impacts on snails (like an abundance of floating dead snails for example, or disappearance of periphyton) to tie to the dramatic snail decline in southern WCA3A between 2003-2004. As far as this issue compared to DSV, it is very different. There is an abundance of information on DSV and their role in explaining kite trends -- in this case however, there is disagreement that DSV is even an appropriate hydrologic metric by which to analyze kite responses (see comments 14, 42, and 58, and 61 above). This comment also speaks to the issue of how topographic information or depths are needed to understand how kites are distributed within and among wetlands. The snail issue is more related to a lack of sample size, not how well the observations accurately reflected the on-site conditions associated with a decline in snails between 2003-2004.

M. Cook

External Review Comments: Phase 2

Com-ment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
1	Chapters 1 through 9; general comments	My primary task in this review was to focus on chapters 10 and 11, but I first felt it necessary to read and provide a brief overview of the entire document. The first nine chapters are an excellent synthesis of snail kite and apple snail research from the past 40 years in Florida. The chapters are well written, logically ordered and provide a succinct review of all science pertinent to managing kite populations. Moreover, although the original review material is often complex and technical in nature, the information is presented such that it is easy to read and accessible to the lay reader. The authors provide interesting insights into the history and development of kite research, but more importantly they expose important differences in opinion among researchers, provide useful critique of scientific conclusions and reveal important gaps in the scientific knowledge. This information provides the foundation for important recommendations in later chapters. Compiling and synthesizing this information was clearly no easy task and I congratulate the authors on an excellent and very useful piece of work. I foresee this document being a key tool in the future management and recovery of the snail kite.	Mark Cook	Acknowledged.

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Com-ment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
2	Chapters 10 and 11; general comments	In general, I agree with the recommendations in chapter 10 and find them comprehensive in scope. I have no issue with the recommendations themselves. However, I am a little disappointed with the lack of specific hydrologic recommendations available for water managers. Indeed, I believe there is only one recommendation (10-D-4) that provides a tangible set of hydrologic targets. I understand that many of the hydrologic targets have not yet been defined and agreed upon by the scientific community, and attempts are being made to improve the data that support them (e.g., by employing EDEN), but clearly these targets are required as soon as possible and developing them should be one of the top priorities of the proposed recovery team. If managers are the focal audience of this document then it may also be pertinent to consider slightly restructuring the two chapters. While the current organization is logical from a scientist's perspective, for a manager it is difficult to locate the relevant recommendations as they are mixed among the other recommendations. One possible approach is to have two categories for chapter 10: 1) management based recommendations (e.g. those pertaining to water management, conservation, population management etc) that are targeted towards the water management districts, FWC and FWS, and 2) those that need to be addressed by a committee such as the Recovery Team (e.g. refining the multi-species recovery plan, annual assessment reports, communication, etc). Since monitoring and research are closely linked, the monitoring recommendations could join the research recommendations in chapter 11. Such an organizational structure may allow readers to target the relevant recommendations more easily. I certainly agree that the recommendations and research need to be prioritized (line 5138). However, I think this is a task for the Recovery Team rather than the current authors and as such can wait until a subsequent edition of the report. To aid this process, I recommend developing a series of conceptual ecological models comparable to that used in Gawlik's (2002) "prey availability hypothesis". These could be published in a future addition of this document. Specific comments related to the recommendations are discussed below.	Mark Cook	Regarding your first point, we have added language addressing the need for specific hydrologic targets, and the fact that additional analyses or meta-analyses are needed for this purpose. Conducting new analyses was outside of the scope of this report. We added text addressing this overall topic in various places in the report, including Chapter 10. In consideration of the second comment regarding reorganization, we have reorganized Chapter 10; we still maintained monitoring recommendations in this chapter, but combined management recommendations for kites and snails. The recs are still split into 4 categories, but all of the management recs are now together. Regarding your third comment, we agree that the prioritization of the research recommendations would be best conducted by the Recovery Team / Review and Advisory Team. However, we did add to the introduction of Chapter 11 a discussion of some potential prioritization criteria.

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Com-ment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
3	p.158; line 4601; A-1	I agree with this general recommendation and might also include 'effectively manage' with 'Conserve'. However, as discussed in the general comments, water managers require more than general recommendations to manage for the kite, they also need specific details such as which habits are most in need of conservation/restoration/management as well as details on when and how to manage them. For instance, which are the peripheral habits (line 4609) that are of potential benefit to kites and how should they be managed during extreme hydrologic events? How should key habitats such as Lake O and WCA-3A be managed hydrologically, both in the long-term for habitat management and annually with respect to snails and kites?	Mark Cook	As suggested, we added "effectively manage" to the recommendation. As described in the introduction to the General Recommendations, these few recommendations were not intended to present specific, numerical recommendations, but rather overall guiding principles. We have also added some new text to the introduction of this chapter to address this. Note that recommendations in this report were to be based primarily on information that was available from the existing literature. Making specific recommendations for specific wetland units requires a meta-analaysis that incorporates available snail and kite data and the recent hydrologic history of the wetland units critical to kites; this has yet to be done. Note also that there are more specific recommendations later in this chapter.
4	p.158; line 4620; A-2	This recommendation is important but it is not clear why the scale issue is limited solely to population responses? Why, for instance, is the relevant temporal scale of managing kite reproductive success not discussed? Perhaps this recommendation should be more inclusive and discuss a range of management strategies for kites, snails and their habitats, along with the appropriate scales for their management.	Mark Cook	Again, the intent of these first 3 General Recommendations was to provide an overall context for conservation/managemet. We agree with the first part of the comment and expanded the recommendation statement accordingly. The point of this recommnedation as originally stated (see background material) was that the kite is a "boom or bust" species, and it may have some bad years; it is most important to focus on the longer-term trends. We did not agree with the second part of the comment to provide more management specifics here.
5	p.159; line 4631; A-3	This is an important recommendation but again specific details are missing from a water management perspective: i.e., which wetlands need to experience periodic dry downs and at what frequency? Clearly the jury is still out on the answer to the later question but data are available and a consensus among scientists needs to be reached soon. Even an estimated target that can be used within an adaptive management framework is better than no management at all.	Mark Cook	See above comments regarding the general nature of this and the previous two recommendations. Specifics are addressed elsewhere in the recommendations.

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6	p.159; line 4650; A-4	A recovery team is certainly needed and every effort should be made to bring a functioning and effective working group to fruition. In addition to the four important tasks provided, I would also consider adding a fifth - developing a communication plan to disseminate key information to resource managers and the public (similar to recommendation E1) . I strongly advocate two approaches that have worked extremely well for managing and bringing attention to wading bird populations. The first is a multi-contributor annual report that might include summary sections on kite nesting effort, nesting success, snail populations, habitat conditions, status of recovery, new findings etc. Such a report not only provides a useful annual reference for researchers and managers but is peerless in its ability to communicate the plight of a species to all levels of resource management at multiple agencies as well as to the local and national press. Recommendation B-3 could be part of this report. The second recommendation is the development of a habitat suitability index for kites and snails, which can be used by water managers to assess habitat conditions in real time or be used to predict various restoration or management scenarios using GIS based spatially explicit mapping tools (e.g., Beerens et al. 2011). Such HSI tools are currently being used to great effect for wading birds. A potential sixth recommendation (if it has not been considered already) is to produce a series of performance measures for the kite, snail and habitat. For example, a kite performance measure might be based on expected nesting effort and reproductive success required to promote population growth. Beerens, J.M., D.E. Gawlik, G. Herring & M.I. Cook (2011) Dynamic habitat selection by two species with divergent foraging strategies in a fluctuating wetland. The Auk	Mark Cook	Good suggestions. We added the development of a communication plan (possibly including a multi-contributor periodic report) and the need to develop performance measures to the tasks of the recovery/advisory team. We also added a new recommendation for the development of a habitat suitability index.
7	p.160; line 4687; B-1	I agree with this recommendation but again more specific are needed. The Multi-Species Transistion Strategy is a welcome improvement on the single species approach to restoration/management, and is the first attempt to define hydrologic management targets for kites/snails and habitat in the Everglades; yet this particular application is limited. Not only is it restricted in space (WCA 3A), but the models were based on data from a limited number of gages (the 'three-gage average') rather than on spatially explicit hydrologic modeling (e.g. EDEN). Thus, it is not surprising there are concerns regarding the strategy (line 4702). To better manage for kites water managers require a more refined and robust set of habitat suitability models that better define the hydrologic requirements of kites, snails and habitat at the appropriate temporal and spatial scales.	Mark Cook	We acknowledge the comment and attempted to address it here by making the recommendation more broad; the point here was to use the approach. The particulars of gages used, etc. are details that go beyond what is being recommended. We also addressed the subject of the need for specifics in several other places in this chapter and elsewhere.
8	p.161; line 4707; B-2	Good recommendation but again more details are needed (see comments to B-1)	Mark Cook	Agree, but have addressed that need in other recommendations.
9	p.161; line 4735; B-3	This annual wetland assessment could be part of a larger, more encompassing report discussed in comment 6	Mark Cook	We noted the link to the earlier recommendation as suggested.

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Com-ment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
10	p.165; line 4827; C-1	In additon to ENP, I also recommend regular monitoring in the District's Stormwater Treatment Areas.	Mark Cook	A stated goal of restoring hydrology to ENP is to improve conditions for native flora and fauna, whereas the STAs are designed to remove nutrients as water flows south into WCAs and eventually ENP. This recommendation emphasizes ENP and its hopefully future role in drawing kites to this part of their historic range. The STAs are now included in the areas monitored during during annual population surveys and nest monitoring (see Cattau et al. 2011).
11	p.166; line 4864; C-4	Kite researchers may also want to consider exploiting citizen science programs to determine kite locations. A particulalr useful approach is ebird developed by the Cornell Lab of Ornithology and National Audubon Society. Moreover, there are many well respected birders in Florida that regular report avian sightings online. Even if such data are not appropriate for analyses they could be useful reference points for more focused monitoring.	Mark Cook	Helpful information. We incorporated the suggestions into the recommendation.
12	p.170; line 4966; D-4	Excellent, these data can be used by water managers!	Mark Cook	Great. The recommendation has been modified somewhat (based on comments from other reviewers) to emphasize the point that these are the best data we have at this time, but that the upper end of the water level range may need revising as more work is conducted.
13	p.179; line 5252; 11-A-8	Could the prevelance of pathogenic parasites in apple snails, including *P. insularum,* be a useful surrogate here?	Mark Cook	We are not sure; we have added a sentence in the recommendation background to address the question.
14	p.181; line 5316; 11-B-5	Consider examining the lower thermal tolerance of the *P. insularum* in relation to *P. paludosa.* As with non-native fishes, there may be the potential to control populations during cold snaps (see Schofield et al. 2010). Nate Dorn and I also have some data from LILA which suggest that mollusc populations (although not apple snails) are greater in flowing than non-flowing macrocosms.	Mark Cook	We believe that dispersal (which we have added to the recommendation) is a higher priority at this time than temperature tolerance. However, we have added mention of temperature tolerance to the recommendation background.

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Com-ment #	Reference Information (Chapter, Page, Line)	Comment	Reviewer	Pomacea Project Response
15	p.182; line 5328; 11-B-6	In freshwater ecosystems drying disturbances can reduce predatory vertebrates or invertebrates leading to transient or permanent changes in prey community structure and recruitment pulses of predator-sensitive prey taxa. For example, a recent experimental study has shown that dry-downs have a significant predator release (fish removal) effect on crayfish population, which in turn may affect white ibis nesting responses. Understanding the strength of predator-snail interactions and predator control of snail populations would be very informative to managers, especially as they relate to hydrologic conditions and proximity to canals.	Mark Cook	Acknowledged.
16	p.183; line 5373; 11-B-8	Why limit this to pristine ridge and slough habitats? Wouldn't it be more appropriate to examine a variety of ridges and sloughs types and employ a model selection approach to understand the habitat characteristics that are most suitable for snails?	Mark Cook	We incorporated the comment in the recommendation.

APPENDIX C: ABANDONING "DROUGHT" FOR DEPTHS

REVISITING "DROUGHT SEMANTICS"

The foundation for the current snail kite monitoring program and our understanding of how kite demography responds to a dynamic landscape was established in the technical report *The Demography and Movements of Snail Kites in Florida* (Bennetts and Kitchens 1997a). The authors devoted a section of their chapter on management and conservation to "Drought Semantics." They pointed out that despite the critical impact of water levels and drought conditions on kites, "it is surprising that these authors [referring to older publications on snail kites] have not defined drought sufficiently to enable an independent observer to designate a given year as a drought year." Bennetts and Kitchens (1997a) derived a quantitative approach to designating drought years for wetlands important to kites (see below), but before describing that approach and its limitations, we revisit the semantics of the term drought.

Drought primarily refers to a deficit in rainfall in a climate context and is not necessarily an appropriate term to describe water levels. The term drought has even less meaning in the context of water levels in peninsular Florida wetlands and lakes, where water levels are affected by management. So, for example, in 1996 central Florida did not experience a drought (see Bennetts and Kitchens 1997a), but the managed drawdown (a 1.7 m, 5.6 ft, decline) of Lake Kissimmee resulted in the drying out of more than 80% of the littoral zone (see Darby et al. 2004). In 2001, generally considered a drought year (see Steinman et al. 2002), Lake Okeechobee (LOKEE) was dry from January to July (and had been dry for much of 2000), while Water Conservation Area (WCA) 3A remained flooded all year in its southern portion (south of latitude 25° 50') (and had not been dry in 2000). The portions of WCA3A that did dry out (north of latitude 25° 50') were dry from approximately April to June in 2001 (see additional detail below). Ecologically, these differences are important; apple snails, for example, were impacted to a much lesser degree in WCA3A than on LOKEE. We advocate for moving away from the word "drought" to describe hydrologic conditions (although of course they are related), and to a focus on depths and the duration and spatial extent (with geographic reference) of actual dry down condition (i.e., water table below ground level).

As presented in Chapter 5, Beissinger (1995) wrote that the Everglades "is one of the least seasonal wetlands in the Neotropics" (i.e., that water depths in the Everglades do not fluctuate nearly as much as in other wetlands). This may be true, but what characterizes least or most seasonal, and what constitutes a moderate or severe drought is a matter of degree. We need quantifiable metrics

that reflect how kites and snails respond to the seasonality (as well as longer-term fluctuations) in water levels within the kite's range.

Bennetts and Kitchens (1997a) developed a drought intensity score (also called drought score value, or DSV, per Martin et al. 2006a) that was applied to a series of papers on kite response to water level conditions (e.g., Drietz et al. 2001, Bennetts et al. 2002, Martin et al. 2006a, Martin et al. 2008). DSVs are based on the number of standard deviations (SD) above or below some long-term average water stage for a wetland unit. Bennetts and Kitchens (1997a) designated a wetland as being in drought condition if water stages for a year were 1SD below the long term average; 2SD was considered an extreme drought year. Martin (2007) based a hierarchical clustering analysis on the same approach to identify years as wet, moderately dry, and drought (Martin 2007 was cited in Martin et al. 2006a and 2008 for details on methods). Martin (2007) reported 1992 and 2001 as drought years for WCA3A, compared to a long-term average for 1992-2006. The DSV for 2001 in WCA3A was -1.92 (Martin et al. 2006a; 1992 DSV not reported). Martin et al. (2008) concluded that for kite conservation, in light of a declining population starting in 2000 or 2001, moderate drying events (2000, 2002, 2004), and especially drought conditions, should be avoided in WCA3A and other critical kite use habitats. However, Bennetts and Kitchens (1997a) reported a drought intensity score of +0.14 SD for 1992 (i.e., slightly above the long-term average). The main reason behind this discrepancy was that the Bennetts and Kitchens (1997a) long-term average was based on stages in WCA3A from 1969-1995, which overall included significantly lower water levels than the 1992-2006 period reported by Martin (2007) (see Figure C-1).

We do not question the validity of assigning *relative* drought years *within* a wetland for some period (e.g., 2001 was the lowest water level year in WCA3A from 1992-2006), but we find it misleading, especially from a management perspective, to conclude that droughts (which imply, but do not necessarily mean, dry down conditions) should be avoided. Overall, the snail kite population was stable or growing during the relatively drier 1980s- early 1990s based on the estimated number of birds from annual counts (controlling for effort, observer, site, and water level; Bennetts et al. 1999a, Figure 3-7); based on that era of water stage fluctuation, 2001 water levels were fairly typical, and yet the 1980s- early 1990s era of relatively dry conditions (more frequent drying out of WCA3A) supported kite nests in the hundreds in some years (e.g., Bennetts et al. 1988). Kitchens et al. (2002) noted that kites abandon an area when depths fall below ~10 cm; from January to April 2001, depths exceeded 10 cm for all but a few weeks in WCA3A north of 25° 53' and for only a few days further south in WCA3A (Figure C-2). Martin et al. (2006a) concluded that kites moved out of the Everglades region less than expected based on their 2001 DSV (-1.92), but depths had not fallen to the levels associated with massive dispersal in the 1981 and 1985 droughts documented in Beissinger

Figure C-1. Water stage in WCA3A from gauge at Station 3-65 (Site 3A-28) for 1969-2006. Period for which long term averages were calculated by Bennetts and Kitchens (1997a) (black dashed line) and Martin (2007) (gray dashed line) are shown for reference. Also shown for reference is the ground level at Site 3 (7.74 ft [2.36 m] above MSL; solid black line), as estimated by Darby and Wight (2011); see Figure C-2 for location of Site 3. Drought score values (DSV) for 1985 and 1992 reported by Bennetts and Kitchens (1997a) (^{BK}), and for 2001 as reported by Martin (2007) (^{M}). Arrows point to stage on May 31st of each year.

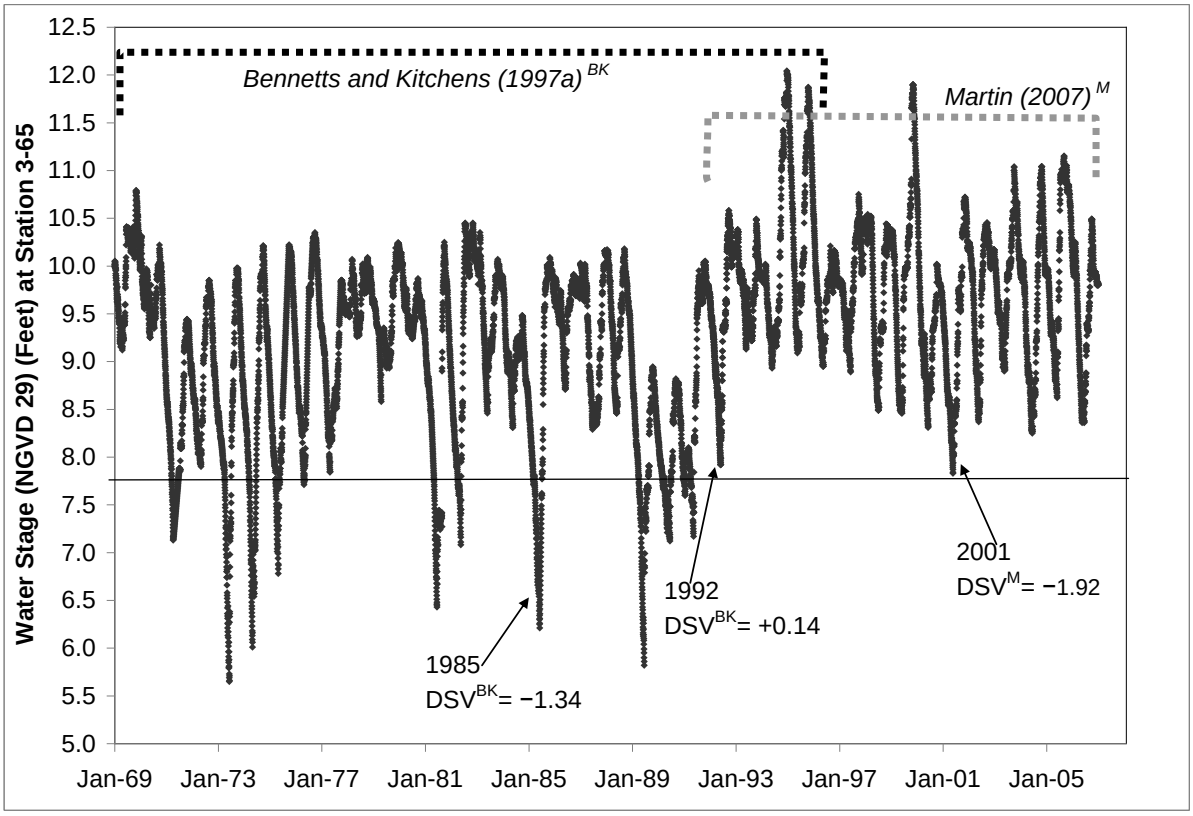
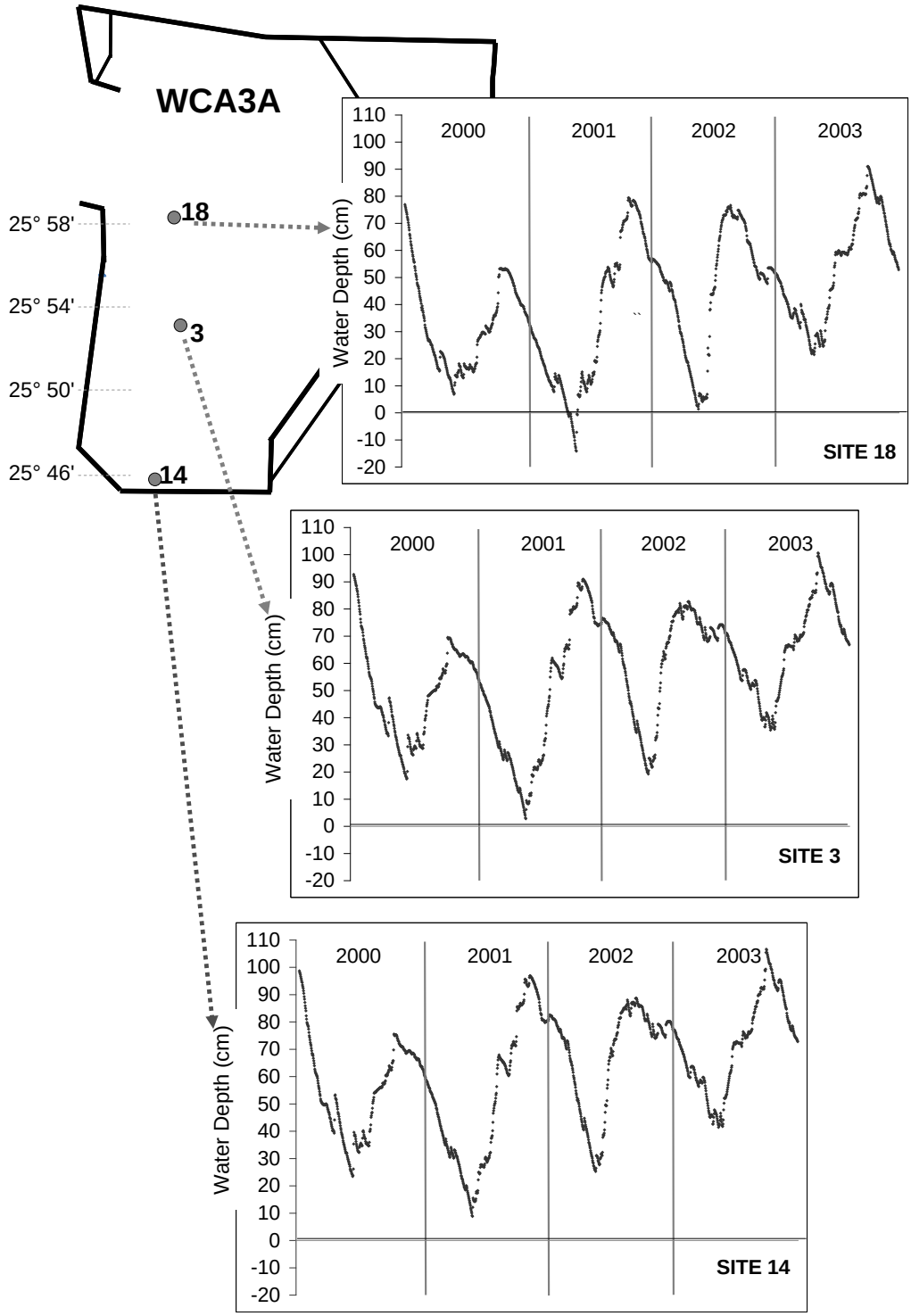


Figure C-2. Water depths from 2000-2003 as reported in Darby and Wight (2011) and Darby et al. (2009). WCA3A Sites 18, 3, and 14 locations as reported in Darby et al. (2005), Karunaratne et al. (2006), and Darby et al. (2009). Water depths were also validated through EDEN for the same time period (see Darby and Wight 2011).



and Takekawa (1983) and Takekawa and Beissinger (1989). Based on Darby et al. (2005, 2009) and Darby and Wight (2011), 2001 and 2002 (drought and moderately dry years per Martin 2007) were some of the best years for apple snail production, and wetter years (e.g., 2003) resulted in a significant reduction in the snail population in the areas sampled. From a snail perspective, kite recovery may require more years like 2001-2002 to repopulate the snails in WCA3A, especially south of latitude 25° 53' (Figure C-2); otherwise, the snail population will likely continue to remain quite low (see Chapters 6 and 7). [Note that no data are available for snails north of 25° 59', so in the future we recommend more spatial analyses of snail distributions in areas like WCA3A (see Chapter 11)].

When looking at actual water depths for 2001 where southern WCA3A remained flooded (see Figure C-2), it would be helpful to know what kite activity was associated with the January to April water levels, and how kites responded to changes in depths as the dry season progressed. [Bennetts et al. (2002) described such a shift in WCA3A in 1994-1995 during extreme high water conditions]. Using a DSV to characterize an entire wetland, especially one as large as WCA3A, and using these values in a quantitative analysis should be interpreted in a very narrow context. At the very least, on-site depths or approximated ground level estimates combined with stage data (e.g., see Bennetts et al. 1988, Darby et al. 2005, Darby et al. 2008) should accompany DSV so the management community can have a sense of what depths are associated with "drought," "extreme drought," or "moderately dry" years. A DSV cannot reliably be used to quantify the occurrence and duration of a dry down (see Figure C-2).

Apple snails, snail kites, and other wetland fauna do not respond to water stage or drought score values (DSV); they respond to water depth. Given the subjectivity of the word "drought," and the uncertainty as to how a DSV reflects actual depths, we recommend a movement towards using actual depths, or the proportion of time at different critical depths, to explain snail kite and apple snail responses to hydrology. The development of the Everglades Depth Estimation Network (EDEN) was a response to the need to quantify ecological responses of plant and animal communities to depths. A tool to identify suitable depths for kite nesting was developed from spatially explicit depth data (Lo Galbo et al. 2010). An example in the context of apple snail egg cluster production (i.e., the number of days during the breeding season at certain depths) is provided in Chapter 8. Dorn et al. (2011) have recently used EDEN data to quantify the response of foraging ibis to changes in water depth in the Everglades.

Note that references cited in this appendix appear in the Literature Cited chapter of the main report.

APPENDIX D: HYDROLOGIC CONDITIONS ASSOCIATED WITH SNAIL KITE NESTING SUBSTRATES AND FORAGING HABITATS

The purpose of this appendix is to discuss what is known of the hydrologic needs of some of the most common snail kite nesting substrates and the vegetative communities (and indicator species) in which kites forage. Thorough coverage of this topic is outside of the scope of this document, but the information provided here gives an indication of the water depths and hydroperiods in which the plants and communities exist. Depth of flooding, hydroperiod, or duration of flooding, and seasonal variation in water levels are some of the most important factors determining the distribution of plant communities (Zaffke 1983). Most often hydroperiod is estimated on an annual basis. Hydroperiod directly affects plant distribution by excluding species that are not tolerant of prolonged inundation and increased water depth, as well as affecting the germination of seeds. Hydroperiod also affects the intensity and frequency of fires. However, based on the information that follows, hydroperiod data alone, especially when a plant or community exists in a wide range of hydroperiods, are not as meaningful as also having seasonal water depth data and information on the frequency of dry downs.

In the snail kite foraging section of this appendix, we focus on the hydrology of wet prairie communities but also present some species-specific information on an important component of these communities in the Everglades, Gulf Coast spikerush (*Eleocharis cellulosa*). Spikerush-dominated wet prairies are also important to apple snail populations, and some of their highest densities occur there.

NEST SUBSTRATES AND HYDROLOGY

The most commonly used woody substrate, willow (*Salix caroliniana*), is addressed in this section, as is the less often used buttonbush (*Cephalanthus occidentalis*). Three common non-woody substrates used by kites for nesting are also addressed— cattail (*Typha* spp.), sawgrass (*Cladium jamaicense*), and bulrush (*Scirpus* spp. [some species now in genus *Schoenoplectus*]).

Woody Substrates

Willow

Coastal-plain willow is the woody substrate most used by snail kites for nesting in many wetlands (e.g., Sykes 1987a, Bennetts et al. 1988, Rodgers 1992, Dreitz et al. 1999). In the Everglades, at the time of Loveless's work (1959), willow occurred in a wide variety of situations

and among most vegetative community types in the Everglades. Once established, willow appears to be little affected by high water levels (Loveless 1959, Zaffke 1983). Bennetts et al. (1988) found water depths of 20-80 cm (7.9-31.5 inches; at the time the first egg was laid) under the vast majority of 281 nests, and more than 95% of the 281 nests were located in woody vegetation, especially willow. The shrub propagates by seed or vegetatively with preformed root primordia on the stems (Kuzovkina and Quigley 2005). Willow also reestablishes vigorously from coppiced stumps (Kuzovkina and Quigley 2005). Willows develop adventitious roots from their trunks as water depths increase. Loveless (1959) reported willow to be most abundant next to the peripheral levees and interior canals where they may form thick stands. They may also be found on some tree islands where the original vegetation was lost to fire, around alligator holes, and in the ecotone between tree islands and wet prairie.

Continuous flooding results in the eventual loss of woody vegetation (e.g., U.S. Department of Interior [USDOI] 1972, McPherson 1973, Worth 1983, Alexander and Crook 1984, all cited in Bennetts et al. 1988), although willow tolerates prolonged inundation better than many woody species (Loveless 1959). At the time of the writing of Bennetts et al. (1988), willow was reportedly receding in wetter/deeper areas of Water Conservation Area (WCA) 3A (McPherson 1973), and its coverage was reduced in WCA2A and the deepest portions of WCA1 due to prolonged flooding (USDOI 1972, Worth 1983, as cited in Bennetts et al. 1988). A study in LNWR suggested that major changes in the vegetation would occur if areas were inundated for more than five years (USDOI 1972). According to Bennetts et al. (1988), kite use of WCAs 1 and 2A decreased following prolonged flooding and subsequent loss of shrubs and trees (although they do not claim a cause-effect relationship between loss of woody vegetation and decreased kite use, noting the likelihood of additional important factors); likewise, the authors recorded relatively few kites in the deepest areas of WCA3A where the loss of woody vegetation was most evident. Additionally, there were reports of the loss of willow heads in the littoral zone of Lake Okeechobee (LOKEE) after prolonged high water between 1973-1981 and through at least 1989 (reviewed by Kitchens et al. 2002).

At least three studies (David 1996, McPherson 1973, and Lowe 1986) estimated hydroperiods for willow in either WCA3 or the Upper SJM (Kitchens et al. 2002). In the David (1996) study in WCA3A, conducted from 1978-1984, willow occurred in about 5% (30) of the quadrats sampled. The range in annual duration of flooding was 36-100% among the quadrats, and mean water depth was 38 (±21 SD) cm (15 [±8.2 SD] inches). The other estimate for WCA3 reported a range of mean values of 69-75% (McPherson 1973, as cited in Kitchens et al. 2002). In the Upper SJM, willow was inundated annually about 72-80% of the time (Lowe 1986; no

water depths provided). Additional information on hydroperiods and water depths for woody communities in which willow occurred is also summarized in Gann and Richards (2009). Willow was included in bayhead swamp forest, bayhead, and willow head communities; water depths and hydroperiods varied among the communities and locations reported (see Table 2-4 of Gann and Richards 2009).

Buttonbush

Buttonbush has been used as nesting substrate in the Everglades and central Florida lakes and marshes. From 1987-1991, kite nests were found in buttonbush about 16% of the time on Lake Kissimmee (LKISS), 2.4 % on Blue Cypress Water Management Area/Conservation Area (BCWMA/CA), and 1.4% on LOKEE (Rodgers 1992). Throughout its range, buttonbush is best adapted to swamps, marshes, and shorelines with saturated soil and full sunlight (Natural Resources Conservation Service 2006), and tolerates water depths up to 0.9 m (3 ft). In a study of the relationship between hydrology and vegetation patterns in a floodplain marsh in the Upper St. Johns River Basin, buttonbush was found to occur at elevations in the marsh with a frequency of inundation between about 61-78% (but especially in the upper half of the range; Lowe 1986). On LOKEE, buttonbush was inundated for 65-95% of the time (Ager and Kerce 1969).

Non-woody Nesting Substrates

Herbaceous vegetation is most often used as a nest substrate on the Kissimmee Chain-of-Lakes (e.g., Rodgers 1992, Cattau et al. 2007), and, in some years, on LOKEE (Rodgers 1992). The primary means of expansion of most sedges and grasses is vegetative growth, although it is sexual reproduction that preserves long-term genetic diversity (Sklar et al. 2002). The survival of seeds and seedlings is affected by hydrologic factors, including water inundation.

Cattail

Cattail (*Typha domingensis* and *T. latifolia*) is one of the most often used nesting substrates on the Kissimmee Chain-of-Lakes (e.g., Rodgers 1992), and in some years on LOKEE (Rodgers 1992) and BCWMA (Dreitz et al. 1999). However, in many situations this plant is considered undesirable because of its tendency to spread rapidly and displace other species. The expansion of cattail has been reported throughout the Everglades and other parts of Florida (e.g., see, Newman et al. 1998, Sklar et al. 2002, Surratt et al. 2012). In northeastern WCA2A, cattails have replaced sawgrass, probably due to nutrient enrichment and prolonged hydroperiods (Urban et al. 1993). Soil disturbance may also lead to cattail expansion (Lodge 2010). Although there is

a considerable amount of overlap in the hydrologic tolerances of cattail and sawgrass (Gann and Richards 2009), there are some differences. Differences between the two species arise due to their different leaf morphology, anatomy, and physiology (Sklar et al. 2002). These differences include cattail's ability to actively transport oxygen to its roots when it is growing in deep water.

A study comparing Southern cattail (*T. domingensis*), sawgrass, and jointed spikerush (*Eleocharis interstincta*) found that when the three species were grown in low nutrient and low water (15 cm [6 inch] and 30 cm [12 inch]) conditions, there were no growth differences between the three (Newman et al. 1996). However, when grown in low nutrient and high water conditions (60 cm [23.6 inches]), Southern cattail had significantly greater growth (biomass) than the other two species. Also, when grown in high nutrient conditions, Southern cattail had significantly greater growth than the other species at all three water depths. Field studies in Everglades wetlands revealed that increased phosphorus concentrations were related to cattail expansion and declines in either sawgrass marsh and wet prairie communities (Doren et al. 1997) or macrophyte species richness (Childers et al. 2003).

Southern cattail is able to grow in water more than 1.2 m (3.9 feet) deep for sustained periods of time (Grace 1987 and 1988). Lodge (2010) noted that cattails do not typically occur in deeper marsh communities in the Everglades, such as peat-based wet prairies and sloughs, even though the water there is not too deep for them. Based on a two year pond experiment, Southern cattail grew in water depths ranging from -5 to 115 cm (Grace 1989). It grew in highest densities at depths of 5, 22, and 42 cm. The same study found that *T. latifolia* achieved maximum densities in the same range of water depths as T. *domingensis*, but it did not survive in water depths greater than 95 cm. In the David (1996) study in WCA3A, Southern cattail occurred in about 8% of the quadrats sampled; the range in inundation frequency was 63-100% and mean water depth was 24 (±12 SD) cm (9.5 [±4.7] inches). An inundation period of 90-100% was reported for cattail (*Typha* sp.) on LOKEE (Ager and Kerce 1969). Richards et al. (2008) reported Everglades Depth Estimation Network (EDEN)-estimated water depths of 57 cm during the wet season and 15 cm during the dry season for the cattail community identified in 2005 Regional Environmental Monitoring and Assessment Program sampling. Hydroperiod calculations from the same project for the cattail community lead to an estimate of 11.3 months of inundation. How much drying out cattail can tolerate is unclear (Gann and Richards 2009).

<u>Sawgrass</u>

In the Everglades, sawgrass is used rarely as a nest substrate (e.g., < 2% of nests in WCA3A in 1986-87 [Bennetts et al. 1988]), but in other portions of the kite's range the plant's

use is more common (e.g., 10% of nests in BCWMA/CA in 1987-91 [Rodgers 1992]). As described in this report, sawgrass is also an important substrate for apple snail egg-laying. Sawgrass is able to survive in a range of water depths, from a dry substrate to depths flooding the lower portions of the plant, but prolonged high water levels will kill it (Gunderson 1994). The plant can tolerate water depths up to 81 or 82 cm (Olmsted and Armentano 1997, Givnish et al. 2008, Gann and Richards 2009). A study of sawgrass germination indicated that germination of seeds was greatest in water-saturated soil, lowest in soil with 10-cm-deep (4-inch-deep) water, and intermediate in 5-cm-deep (2-inch-deep) water (Ponzio et al. 1995). Growth was also faster and survival higher for seedlings under saturated conditions compared to inundated conditions. The regrowth of sawgrass after fire under different hydrologic conditions has also been studied (Herndon et al. 1991). Researchers found that if sawgrass culms were submerged (flooded) after burning, the culm apex died. This means that during periods of high rainfall (e.g., May and June), sawgrass burned down to the culm may not grow fast enough to stay above increasing water levels. The authors found that remnant sawgrass culms were typically 8-14 cm above the water surface right after a fire, and having this amount of remnant culm decreased the probability of widespread mortality from flooding by about 50% during the period when lightning fires were most likely to occur.

Lodge (2010) reported an average annual hydroperiod for sawgrass marsh as 10 months, with a range of < 6 months to nearly continuous flooding (based on Olmsted and Loope 1984, Gunderson 1989, Kushlan 1990, and Gunderson 1994). Estimates from Gunderson (1989) included an average hydroperiod of 317 days/year (or 87%) for dense sawgrass in ENP and 291 days/year (80%) for sparse sawgrass in ENP (based on 32 years of data). Water depths typical during the wet season are 30-45 cm (1-1.5 feet; Lodge 2010). Lodge (2010) reported that taller, denser sawgrass tends to be associated with areas having deeper water, longer hydoperiods, and peat substrates, while more sparse sawgrass stands are associated with shorter hydroperiods and marl prairies (also see Gunderson 1994).

Additional hydroperiod estimates for sawgrass cover a broad range within and among studies; estimates for sawgrass in WCA3A were 31-84% (David 1996) and 76-93% (McPherson 1973, as reported by Kitchens et al. 2002), and in the Upper SJM about 46-83% (but primarily in the 60-83% range; Lowe 1986). Armentano et al. (2006) mentioned three studies (Wade et al. 1980, Doren et al. 1997, and Olmsted and Armentano 1997) that give hydroperiod ranges for sawgrass-dominated marsh of 5 to 9 months [~42-75%] per year. Zaffke (1983) reported an inundation range of 15-94% for sawgrass in WCA3A. Richards et al. (2008), using six years of EDEN data, estimated hydroperiod and wet and dry season water depths in samples from the

Everglades from WCA1 to ENP. The sawgrass community had a hydroperiod of 11.0 months, wet season water depths of 58 cm, and dry season depths of 18 cm. Although sawgrass is not addressed in the Foraging Habitat and Hydrology section that follows, see the list of references in the section; some, particularly Richards and Gann (2008), contain additional hydroperiod and water depth data on sawgrass.

Bulrush

Bulrush (*Scirpus* [some species now in genus *Schoenoplectus*]) species large enough to support kite nests are found in fresh water marshes and swamps and lake and pond margins. Soft-stem bulrush (*Scirpus validus* [now *Schoenoplectus tabernaemontani*]) was the most often used substrate for kite nesting on East Lake Tohopekaliga (East LTOHO) during 1987-1991, and it was used to a lesser extent on LTOHO, LKISS, and LOKEE during the same period (Rodgers 1992). Inundation periods for bulrush species on LOKEE were 85-95% for three-square (*S. americanus*) and 95-100% for soft-stem bulrush (Ager and Kerce 1969). On LKISS, Darby (2006) found that, at its lowest limit, soft-stem bulrush existed at lower elevations than the other herbaceous plants in the littoral zone (e.g., pickerelweed [*Pontedaria cordata*] and torpedo grass [*Panicum repens*]). In an experiment using controlled environmental chambers to study the growth of soft-stem bulrush (from field-harvested rhizomes), water level drawdown (to below ground level) was found to negatively affect plant growth (measured by an increase in the proportion of dead stems; Hunter et al. 2000). Microcosms were drained and refilled over a 4- or 12-day period. Both stem and root production were higher in microcosms that were constantly flooded, compared to those with fluctuating or drawn down (to below ground level) water levels. On the opposite extreme, the upper limit for robust growth appears to be ~1.2 m (3.9 feet; Payne 1992).

FORAGING HABITAT AND HYDROLOGY

As discussed throughout this document, snail kites commonly forage in wet prairie habitats in the Everglades and more northern marshes (e.g., BCWMA/CA), as well as in sloughs. On the Kissimmee Chain-of-Lakes and Lake Istokpoga, kites forage in lake littoral zones with emergent vegetation in relatively low stem densities (Darby 2006, Darby 2009). These littoral zones may be dominated by stands of maidencane (*Panicum hemitomon*) and spikerushes (Bennetts et al. 1994). At LOKEE, the littoral zone has been described as an extensive system of diverse marsh habitats that possesses components of both graminoid marsh (slough and wet prairie communities) and the northern lakes (Bennetts and Kitchens 1997a). Kitchens et al.

(2002; page 192) reported that, based on analysis of more than 5,000 locations of radio-tagged birds (i.e., Bennetts and Kitchens, unpublished data), kites forage in wet prairie communities "to a far greater extent" than in sloughs. Although based on fewer data, Bennetts et al. (2006) drew a similar conclusion based on direct observations of foraging kites. Even though wet prairie communities appear preferable for foraging, sloughs are readily used (Kitchens et al. 2002, Sykes 1983b, Bennetts et al. 1994, Sykes et al. 1995). In this appendix, we present information on the hydrology of snail kite foraging habitats, with particular emphasis on wet prairies. Although the focus here is on the kite, suitable snail kite habitat includes a sufficiently high snail density to support foraging (see Chapter 7). Maintaining a sufficiently high snail density depends on egg production along the ecotone created by sawgrass and wet prairie (see Chapters 4, 6). Hydrologic conditions to support sawgrass were described previously in this appendix.

In the past, there has been disagreement over the hydroperiod length required for snail kite habitat (Bennetts and Kitchens 1997a [p. 110-111]). Older publications and reports suggested that continuous inundation (or hydroperiods of 100%) was required for kites, primarily due to accessibility to snails (e.g., Howell 1932, Stieglitz and Thompson 1967, Beissinger 1983 and 1988). More recently, however, the adverse effects of continuous inundation to the habitat (e.g., the loss of woody vegetation for nesting, roosting, and foraging perches, and the loss of emergent herbaceous species needed by apple snails) have been pointed out (see summaries in Bennetts and Kitchens 1997a, Kitchens et al. 2002, Zweig and Kitchens 2008). Based on a 14-year hydrologic assessment by the USACE (for 1969-1982), Bennetts et al. (1988) reported that kites nested in WCA3A in areas having hydroperiods of about 84-99% days inundated. After subsequent work, they reported a range of 80-99%, with a peak around 90% (Bennetts and Kitchens 1997a). However, snail kites foraging during non-breeding periods often use habitats with shorter hydroperiods, as low as about 70% (Bennetts and Kitchens 1997a). These authors also made an important point that in most wetlands with a significant topographic gradient (e.g., WCA3A), kites did not use the habitats with the longest hydroperiods. They further reported that kites may use both shorter hydroperiod areas (e.g., wet prairies) of longer hydroperiod wetlands (i.e., sloughs or lakes) and longer hydroperiod areas (e.g., sloughs) of predominately shorter hydroperiod wetlands (e.g., graminoid marsh).

Another important hydrologic aspect of a given wetland is the interval between drying events. This interval, which may be expressed as the average number of years between drying events, may be preferable to use (compared to hydroperiod) because it is more specific and captures conditions longer than one year that influence plant communities. However, the term "drying event" must be defined (Bennetts et al. 1988). Bennetts and Kitchens (1997a), for

example, defined a drought as > 1 SD below the average minimum annual water stage (also see Appendix C). In their assessment of dry down intervals for the specific habitats used by kites in the WCAs, Bennetts et al. (1988) found dry down intervals of 1.6 to 5.3 years (minimum to maximum dry down intervals), but the periods of record upon which the estimates were based is unclear. The area with an interval of 5.3 years (WCA2A), however, also experienced a decline in use by kites. Results of this and other analyses of Bennetts and Kitchens (1997a) disagreed with the suggestion by Beissinger (1995) that kite populations need habitat with intervals between droughts of more than 4.3 years. Based on their work, Bennetts et al. (1988) stated that the most suitable hydrologic conditions for nesting snail kites are a dry down interval of > 1.7 years (thought to be long enough to maintain apple snail populations and slough communities) and < 5 years (thought to be short enough to maintain woody vegetation for nest sites). They further reported that drier areas may be used by foraging kites on occasion, as long as the areas are wet enough to support apple snails.

An earlier draft of this report included a table with hydroperiod information, and water depths when available, for habitat/vegetation types used by snail kites for foraging in Florida. The habitats/species addressed included wet prairie (Gulf Coast spikerush, maidencane, Tracy's beakrush [*Rhynchospora tracyi*]), slough (white water-lily, bladderwort [*Utricularia* spp.]), and lake littoral zone (pickerelweed, bulltongue arrowhead [*Sagittaria lancifolia*], bulrushes [*Scirpus* spp. {some species now in the genus *Schoenoplectus*}], and tape grass [V*allisneria americana*]); the species listed may occur in more than one of the three community/habitat types. We have removed this table and replaced it with a list and brief description of studies that present hydroperiod, water depth, and other information, on these and other species of interest. Rather than duplicate information that appears elsewhere, readers are referred to these studies, especially Richards and Gann (2008), which includes an extensive literature review of hydroperiod and water depth information. The list is provided at the end of this section.

Zaffke (1983) reported that extended hydroperiod and increased water depths from ponding in southern WCA3A led to the replacement of wet prairies in that area with sloughs; the sampling sites in the area experienced hydroperiods of 80-100% and maximum water depths of over 3 ft (>0.9 m). More recently, Zweig and Kitchens (2008) discussed how the trend toward white water-lily-dominated deep sloughs had been reported by others in 1990 in the southern end of WCA3A due to impoundment. However, as the hydrology of the area shifted towards longer hydroperiods and deeper water since that time (i.e., starting around 1991, as discussed elsewhere in this report), plant communities have also changed further north in WCA3A (Zweig and Kitchens 2008). For example, *Rhynchospora* flats were no longer found within their study area.

Extensive maidencane flats also no longer occurred in their study area, but these flats were observed by the authors outside of the study sites and by other researchers relatively recently (e.g., Karunaratne et al. 2006, Bennetts et al. 2006). Zweig and Kitchens (2008) found evidence of wet prairie being replaced by deeper sloughs in as little as four years.

As stated above, kites forage in the littoral zones of central Florida lakes. These zones, dominated by emergent species such as maidencane and spikerushes (Bennetts et al. 1994) have hydroperiods in the range of 50-90% (Sincock and Powell 1957, as cited in Kitchens et al. 2002). Kites may forage to a greater extent in the deeper areas of this zone (Kitchens et al. 2002), although, as described in Chapter 3, they may also forage in very shallow lake edges under some conditions (Dave Mellow, Univ. of West Florida, pers. comm.). Areas at lower elevations may be dominated by yellow cow-lily (*Nuphar advena* [=*N. luteum*]), which may be undesirable for visual hunting (Kitchens et al. 2002) and can provide a poor habitat for snails (Darby et al. 2004). Varying amounts of additional information are available on the various species of interest. For example, a moderate amount of information is available on Gulf Coast spikerush (a dominant species in Everglades wet prairie associations on peat; Gunderson 1994). Gulf Coast spikerush was also reported as the third most common species across the Everglades ecosystem (Stober et al. 2001). Information is available on growth at different water levels (e.g., Edwards et al. 2003), seed and vegetative propagation in relation to water levels (e.g., Macek et al. 2006, Williges and Harris 1995), and the plant's ability to tolerate and respond to fluctuating water levels (e.g., Edwards et al. 2003).

Edwards et al. (2003), using mesocosms, studied how the plant acclimated to water depths of 7 and 54 cm (2.8 and 21 inches), and to changing between the two depths. They found that the plant grew differently in shallow versus deep water. After 80 weeks, plants growing in 54 cm (21 inches) produced: fewer, but taller and thicker shoots; fewer ramets; less biomass; and greater shoot biomass compared to root and rhizome biomass (Edwards et al. 2003). Shoot heights above the water surface were similar between the two treatments, so there were substantial differences in shoot lengths between plants in shallow versus deep water. [A particular shoot length above the water is apparently required for adequate aeration of plant organs belowground in this and other spikerush species (Busch et al. 2004)]. When plants growing in shallow water were placed in deep water, their shoots, especially the younger ones, responded quickly by elongating. However, when plants in deep water were placed in shallow water, the emergent shoots died, but were replaced by new shoots. Plants growing in shallow water adjusted more quickly than deepwater plants to rapid changes in water level, but overall, both groups adjusted after about 9 weeks.

Busch et al. (2004) also reported that Gulf Coast spikerush grew better under flooded conditions (10 cm [3.9 inches] and 45 cm [17.7 inches]) compared to dry conditions (-30 cm [-11.8 inches]). Large increases in canopy height, maximum shoot length, and above-ground, root, rhizome, and total biomass occurred with flooded conditions. Root porosity, but not shoot porosity, also increased under flooded conditions, indicating that Gulf Coast spikerush is adapted to flooding. They also compared their results to those for Tracy's beakrush, which grew better under drained conditions. Busch et al. (2004) also reported that spikerush species grow much more during the wet season than the dry season (based on Daoust and Childers 1999).

Macek et al. (2006) also studied the growth response of Gulf Coast spikerush under different water depths, and found results generally in agreement with Edwards et al. (2003) and Busch et al. (2004); however, Macek et al. (2006) included plant responses to more extreme water levels. They found that Gulf Coast spikerush grew best in deeper water (73 cm [28.7 inches]) when considering the total length of the mother ramet and stolon number, but it performed better in water about 40 cm [15.7 inches] deep when considering total above-ground biomass. This was due to vegetative reproduction being greater in shallower water rather than the performance of the mother ramet (Macek et al. 2006). These authors also looked at what happened to the plant under conditions of complete submergence for extended periods of time (followed by emergence). Under water, Gulf Coast spikerush retained only one or two fragile, living shoots. The plant showed the capacity to regenerate after 130 days submerged. Supporting the shoots for more than 4 months exhausted energy reserves and lowered regeneration rates. Based on this and other studies, Macek et al. (2006) reported a depth of ~50 cm (19.7 inches) for optimum growth of the species; at this depth shoots are sufficiently tall and vegetative and generative reproduction are not limited.

References for Information on Hydroperiod and Water Depth

Note: other reports and publications cited in this appendix appear in the Literature Cited chapter of the main report.

Ager, L.A. and K.E. Kerce. 1969. Vegetational changes associated with water level stabilization in Lake Okeechobee, Florida. 24th Annual Conference of Southeastern Association of Game and Fish Commissioners. Pp. 338-351.

This study of vegetation on LOKEE provided information on duration of flooding for a number of species: blunt spikerush (*Eleocharis obtusa)*, matted spikerush (*E. intermedia*),Tracy's beakrush, white water-lily, pickerelweed, bulltongue arrowhead, soft-stem bulrush, three-square, and wild celery (tape grass).

Conti, R.S. and P.P. Gunther. 1984. Relations of phenology and seed germination to the distribution of dominant plants in Okefenokee Swamp. Governors State University, Park Forest South, Illinois.

This study includes information on white water-lily, such as water depths at which the plant grows in the swamp, and the conditions that affect seed germination.

David, G.P. 1996. Changes in plant communities relative to hydrologic conditions in the Florida Everglades. Wetlands 16(1):15-23.

This study reported hydroperiod and water depth data for the following species in WCA3A: Gulf Coast spikerush, maidencane, Tracy's beakrush, horned beakrush, white water-lily, bladderwort species, and bulltongue arrowhead.

Duever, M.J. 1982. Hydrology−plant community relationships in the Okefenokee Swamp. Florida Scientist 45(3): 171-176.

This study presents hydroperiod and water level information for white water-lily and marsh vegetation (e.g., maidencane).

Givnish, T.J., J.C. Volin, V.D. Owen, V.C. Volin, J.D. Muss, and P.H. Glaser. 2008. Vegetation differentiation in the patterned landscape of the central Everglades: Importance of local and landscape drivers. Global Ecology and Biogeography 17:384-402.

The paper presents data on hydroperiod and maximum, minimum, and average water depth for vegetation communities (based on ~550 quadrats) in central WCA3A, southern WCA3A, and southern WCA3B. Information is provided on flooded slough (open water with white water-lily, bladderwort, and periphyton dominant), emergent slough (spikerush species often dominant), and slough-ridge transition, as well as other communities.

Goodrick, RL. 1984. The wet prairies of the northern Everglades, Pp. 185-190. *In* Environments of South Florida: Past and Present II, Gleason , PJ., Ed., Miami Geological Survey, as cited in Kitchens et al. (2002).

This report provided hydroperiod estimates for Gulf Coast spikerush and white water-lily in WCA2 and WCA3.

Jordan, F., H.L. Jelks, and W.M. Kitchens. 1997. Habitat structure and plant community composition in a northern Everglades landscape. Wetlands 17(2):275-283.

This study provides information on mean relative abundance and frequency of occurrence of plant species in sloughs and wet prairies in Loxahatchee National Wildlife Refuge, as well as seasonal variation in average water depth for the communities.

Lo Galbo, A.M., M.S. Zimmerman, D. Hallac, G. Reynolds, J.H. Richards, and J.H. Lynch. 2013. Using hydrologic suitability for native Everglades slough vegetation to assess Everglades restoration scenarios. Ecological Indicators 24:294-304.

This manuscript includes a table reporting water depths, hydroperiods, and dry out or dry down tolerances for Everglades slough vegetation/communities, including white water-

lily, bladderwort species, and spikerush species. Some of the information sources include those included here.

Lowe, E.F. 1986. The relationship between hydrology and vegetational pattern within the floodplain marsh of a subtropical, Florida lake. Biological Sciences 49:213-233.

This study occurred in the floodplain of Blue Cypress Lake in the Upper St. Johns River Basin. Hydroperiod estimates were provided for spikerush species, maidencane, Tracy's beakrush, and pickerelweed.

McPherson, BF. 1973. Vegetation in relation to water depth in Conservation Area 3, Florida, Open File Report, U.S. Geological Survey, Tallahassee, as cited in Kitchens et al. (2002).

This study reported hydroperiod estimates for Gulf coast spikerush and white water-lily in WCA3.

Powers, E. 2005. Meta-stable states of vegetative habitats in Water Conservation Area 3A, Everglades. Master's thesis. University of Florida, Gainesville.

This study presents information, such as on the timing of the maximum water depths during the year, and maximum and minimum water depths, for vegetation community subtypes (or "meta-stable" states) within wet prairie and slough communities.

Richards, J.H., T. Philippi, P. Kalla, and D. Schiedt. 2009. Everglades marsh vegetation: Species associations and spatial distributions from R-EMAP Phase III. Draft report prepared for U.S. Environmental Protection Agency, Region IV. Florida International University, Miami, FL.

This project sampled randomly selected sites across southern Florida marshes (including in the WCAs and ENP) to analyze plant species composition and to relate distributions of species to environmental variables. The report presents hydroperiod estimates and average wet and dry season water depths for species groups, such as Gulf Coast spikerush and white water-lily. The "species groups" designations mean that multiple species occurred in each group.

Richards, J.H. and D. Gann. 2008. Greater Everglades sub-team consulting services to determine plant community depth and hydroperiod optima and tolerances. RECOVER Evaluation Team Support. Final Report to South Florida Water Management District. 62 pages.

This report includes results from a literature review of hydroperiod and water depth information for important Everglades plant species. Table 2 of the report presents information on species including Gulf Coast spikerush, maidencane, Tracy's beakrush, white water-lily, bladderwort species, and bulltongue arrowhead. The studies reviewed in this report may include some of those also listed here.

Stober, Q.J., K. Thornton, R. Jones, J. Richards, C. Ivey, R. Welch, M. Madden, J. Trexler, E. Gaiser, D. Scheidt, and S. Rathbun. 2001. South Florida ecosystem assessment: Phase I/II (Technical Report) – Everglades Stressor Interactions: Hydropatterns, Eutrophication, Habitat Alteration, and Mercury Contamination. U.S Environmental Protection Agency, Region 4, EPA 904-R-01-003.

Chapter 4 of this document reports annual average hydroperiod ranges, annual average ponding depths, and water depths during the wet season for vegetation clusters (water-lily and bladderwort cluster, Gulf Coast spikerush cluster) across the Everglades. It also reports correlations of hydroperiod parameters to plant morphology and soil physiochemistry.

Welch, Z.C. 2004. Littoral vegetation of Lake Tohopekaliga: Community descriptions prior to a large-scale fisheries habitat-enhancement project. Master's Thesis, University of Florida, Gainesville.

This report describes plant communities in the littoral zone of LTOHO and their distribution along environmental gradients. The plants discussed include spikerush species, torpedo grass, pickerelweed, white water-lily, Egyptian paspalidium (*Paspalidium geminatum*), maidencane, and hydrilla (*Hydrilla verticillata*). Information provided includes water depths where the vegetation/communities occurred.

Zaffke, M. 1983. Plant communities of Water Conservation Area 3A; base-line documentation prior to the operation of S-339 and S-340. Technical Memorandum, South Florida Water Management District, Environmental Sciences Division.

This study in WCA3A documented the relationships among water depth, hydroperiod, land elevation, and soil depths to plant communities prior to the operation of two new water control structures. The work, which started in 1977, reported hydroperiod information for the following plant species of interest: Gulf Coast spikerush, maidencane, Tracy's beakrush, horned beakrush (*R. inundata*), white water-lily, and bladderwort species.