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Long-term Trends in Abundance and Habitat Associations of the Everglades Apple Snail

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The Florida apple snail (*Pomacea paludosa*) is of special management interest because survival of the endangered Snail Kite (*Rostrhamus sociabilis plumbeus*) depends on a healthy population of Florida apple snails. In this study, Florida apple snails were sampled across the Everglades from 2005 to 2014. The presence of Florida apple snails was independent of land cover type (slough, prairies etc.), indicating that foraging habitats available to Snail Kites are probably not limiting. However, Snail Kites show a higher use of foraging habitats with lower water depths and snail densities of > 0.1–0.2 snails/m^2 (Darby et al., 2012), indicating that they are more restricted in available foraging habitat than what snail land cover use would suggest. In addition, the abundance of Florida apple snails in samples in the Everglades declined during the course of this study, concurrent with a decrease in the number of nesting Snail Kites in the area.

Keywords: Florida apple snail, Snail Kite, Everglades, water management

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The Florida apple snail (*Pomacea Paludosa*; hereafter, apple snail) is found in tropical/subtropical wetlands (Cordeiro & Perez, 2011). In North America, the species is abundant in Florida and Cuba. The Florida apple snail is the largest native snail in North American freshwater ecosystems (The Pomacea Project, Inc., 2013). The species is particularly abundant in the Florida Everglades, a vast subtropical wetland shaped by water level fluctuations, including periods of extreme inundation and severe drought (Darby et al., 2008). Apple snails have both a ctenidium (gill-like organ) and a lung which allows for better survival in areas with fluctuating water levels (The Pomacea Project, Inc., 2013). Apple snails stay just below the surface of the water and along plant stems, which they use as a substrate to lay eggs. Apple snails are nearly the exclusive prey of the endangered Snail Kite (*Rostrhamus sociabilis plumbeus*) (Darby et al., 2008) and a critical part of the Everglades food web. Concern over the status of the Snail Kite has been the driving force behind the studies done on apple snails in the Everglades (Karunaratne et al., 2006). The dependence of Snail Kites on apple snails makes it important to understand land cover use and abundance patterns of apple snails. This paper examines habitat variables that affect the presence of apple snails and temporal trends in abundance from 2005-2012. The study was done in conjunction with a long-term study of wading bird prey in the Everglades (Gawlik, unpublished data).

Snail Kites have a large habitat range in which to forage because their prey, the apple snail, occurs in a wide variety of wetland land cover types, i.e. sloughs, prairies etc. However, there is a threshold of apple snail density (> 0.1–0.2 snails/m^2) below which, Snail Kites have low capture rates (Darby et al., 2012). Consequently, apple snail density is likely to be more important than habitat type in determining Snail Kite capture rates. Snail Kites are visual hunters, searching for snails in their immediate surroundings while perched or during slow horizontal flight several meters above the water (Sykes, 1987).

The structure of the vegetation also affects the suitability of kite foraging habitat (Bennetts et al., 2006). Snail Kites prefer to forage in sparsely vegetated habitats with a moderate to high density of apple snails. Therefore, although apple snails occur in many wetland land cover types, the requirement for a high snail density and sparse vegetation structure may greatly reduce the area of suitable foraging habitat for kites (Bennetts et al., 2006). Thus, the objective of this study is to understand the conditions that affect the presence of apple snails in the Everglades of Florida.

METHODS

Sample Collection

Apple snails were captured Dec-May each year, 2005-2012 and subsequently labeled as part of long-term study of aquatic prey of wading birds (Gawlik, unpublished data). Sampling occurred in 2013-2014 with no apple snails collected. The sampling design consisted of three strata. Landscape units (LSU) are designated geographical sampling areas which consist of smaller geographical clusters called primary sampling units (PSU). Twenty-five LSUs varied in size from 59-770 km^2 with a mean size of 220 km^2. Two hundred fifty-two PSUs were 400 m x 400 m in size and nested within LSUs. Throw-traps were 1-m^2 (Pierce & Gawlik, 2010) and nested within PSUs. There were two sites within each PSU and each site had two throw-traps when water levels were ~5-60 cm. LSUs and PSUs were fixed throughout the sampling years whereas throw-trap sub-samples were random. Initial PSUs were chosen randomly within an LSU and throw-trap sub-samples were chosen randomly within each PSU. A throw-trap is a box with an open top and bottom. When it is tossed properly, it captures 1-m^2 of the water column and the small aquatic animals in it. A skirt with weights along the bottom edge ensures that there is a solid barrier down to ground surface, thus preventing animals from escaping. A bar seine that fits within the throw-trap is passed through it repeatedly until five consecutive sweeps result in no prey animals.

The vegetation structure of sites was determined by measuring the distance from the center of a throw-trap to the nearest plant in each of four quadrants of the trap, and recording the plant species name. The distance to nearest plant is inversely related to the density of the vegetation. If multiple types of vegetation occurred in the same throw-trap, the number of quadrants in which they occurred was summed and divided by four to determine the percent frequency of each. The plant species with the highest percent frequency was recorded as the dominant plant species for a throw-trap. If percent frequency was equal for more than one plant, all plant species were reported.

Land Cover Type Selection

The original land cover types sampled were categorized as: slough, open prairie, dense prairie, airboat trail, gator trail, boat trail, hole, solution hole, alligator hole, tree island, transition, peat popup, and other. Several land cover types had few samples, therefore we collapsed the categories into more dominant land cover categories of: slough, prairies (comprised of open and dense prairies), trails (comprised of airboat, alligator and boat trails), holes (comprised of holes and alligator holes), solution hole, and other (comprised of other, tree island, transition, and peat popup). In addition, in the several instances where there were multiple land cover types in one sampling site, we chose slough over alligator hole, open prairie, dense prairie, boat trail, and transition, and we chose open prairie over tree island; due to low sampling of the land cover types not chosen, we decided to select the more dominant land cover type out of the two. Samples were not taken when water levels reached ~5 cm or less (Fig. 1). Water depth was recorded at all four corners of the trap at each site. During the analysis, a mean water depth was calculated from the four measurements within each trap and kite foraging habitat was categorized as either suitable or unsuitable based on the apple snail density threshold of > 0.1-0.2 snails/m^2 suggested by Darby et al. (2012). Data were collected in years 2013 and 2014; however, the average water depth data was omitted from these years since we were studying the water depth relative to apple snails and no apple snails were sampled. Vegetation structure (dense vs. sparse) were measured within the throw-traps and compared visually between suitable (apple snail density threshold of > 0.1-0.2 snails/m^2) and unsuitable kite foraging habitat, which has a lower snail density (Darby et al., 2012).

Statistical Analysis

Chi-square test of independence ($X^2=\Sigma[(o-e^2)/e]$) comparing observed and expected values was used to test the null hypothesis that apple snails occur independently of land cover type. Observed values were derived from our collected samples and expected values were calculated as $((N_R \times N_C)/N)$ where N_R is the number of sites with at least one snail in a land cover type, N_C is the number of sites without snails, and N is the total number of sites sampled. In addition, we tested whether the distribution of suitable foraging habitat for Snail Kites was independent of land cover type. Suitable foraging habitat for kites was defined as sites where apple snail density was > 0.1-0.2 snails/m² (Darby et al., 2012). A linear regression was used to test whether there was a change over the study period in the number of sites with apple snails.

RESULTS

Between 2005 and 2012, 876 sites were sampled as part of an aquatic prey study of wading birds. There were 161 sites sampled from 2013-2014. Apple snails were collected in only 54 out of 876 (6%), of the sites (Table 1). Only 9 out of the 54 (17%), of the sites where apple snails were collected met the density threshold of > 0.1–0.2 snails/m² (Darby et al., 2012) in order to be considered as suitable foraging habitat for Snail Kites (Table 2). Seventy-seven percent of the sites sampled were in slough habitats (Table 1.), the remaining 23% of sites were distributed across four land cover types and the other category.

The majority of apple snails (72%) were found in slough habitats (Fig. 2). However, the presence of snails was independent of land cover type, ($X^2 = 5.4$, df = 5, P = 0.37) so the high proportion of snails in slough habitat simply reflected the large number of samples taken in that habitat (Table 1). The distribution of suitable foraging habitat for Snail Kites based on snail density was also independent of land cover type ($X^2 = 6$, df = 5 P = 0.31) (Table 2).

Sites that were designated as suitable kite foraging habitat differed from other sites based on water depth and vegetation structure. Water depth was shallower at suitable kite foraging habitat than unsuitable foraging habitat (mean = 7.6 cm and 14.9 cm, respectively; Fig. 3). Suitable foraging habitat had denser vegetation than did unsuitable foraging habitat (mean distance to nearest emergent plant stem = 8 cm and 16 cm, respectively).

The long-term nature of the ongoing study allowed us to test for changes in the abundance of apple snails over time. We found that apple snail density declined significantly from 2005-2014, except for an increase in 2009 (Fig. 4). Unfortunately, the increased density in 2009 did not have a lasting effect. By 2013-2014, no apple snails were collected. The data in Figure 5 directly corresponds to the decline in number of sites in which apple snails were sampled ($R^2 = 0.45$, b = -0.86, df = 9, P = 0.03).

DISCUSSION

Our finding that apple snail presence was independent of land cover type suggests that Snail Kites should have many foraging habitats available to them, even though the density of snails we sampled was quite low. However, because kites require an apple snail density of > 0.1–0.2 snails/m² (Darby et al., 2012), suitable foraging habitats were actually quite limited. Sites considered suitable for kites had shallower water depths than did other sites. The presence of shallow water in kite foraging habitat is consistent with a previous study that suggested low water levels provide kites with easier access to snails (The Pomacea Project, Inc., 2013; Fig. 3). As with water depth, vegetation structure also acts to limit the distribution of suitable kite foraging habitat. Darby et al. (2012) found that kite foraging habitat had a denser vegetation structure than other sites. Denser vegetation may act as the substrate from which apple snails respire and lay eggs (FWC, n.d.), thus making them visible to foraging Snail Kites.

The long-term decline in snail abundance was a surprising new finding. Apple snails are a key part of the Everglades food web (Karunaratne et al., 2006) and have historically been abundant in the Everglades (Darby, 1998). A sudden decline in this important part of the Everglades fauna is alarming, particularly when considering the importance of the apple snail to the endangered Snail Kite. We considered whether the decline in snails was an artifact of our sampling but ultimately, rejected that explanation. We reasoned that although the number of snails we detected in any given year may be lower than the true density because our samples were collected just as the marsh was drying and snails may have already experienced mortality, any sampling bias toward lower abundance would be the same across all years. Thus sampling bias could not explain a decreased density over time. Furthermore, the statistically significant decline in the number of sites where apple snails were detected (Fig. 5) parallels the decline in number of Snail Kites nesting in the Everglades (Fletcher et al., 2015). According to Fletcher et al. (2015), changes in water management regimes have adversely affected Snail Kite nesting and foraging habitat while also inhibiting populations of Florida apple snails.

Wetland plants and animals are typically found in a particular range of hydrologic conditions (Keddy, 2000) such that changes in either direction will have impacts. For example, increased hydroperiod (number of days an areas is inundated with water) and higher water have had negative effects on Snail Kite habitat (Kitchens et al., 2002). Likewise, the drainage of wetlands has reduced habitat quality for both the apple snail and Snail Kite (Sykes, 1983). Both kinds of hydrologic changes occurred after the northern Everglades was divided into a set of large impoundments. The downstream sections of impoundments experienced increased hydroperiods whereas the upstream sections became drier. These changes were linked to shifts in plant communities (Ross et al., 2003) and declines in wading birds and Snail Kites (Kitchens et al. 2002). Indeed the primary goal of Everglades restoration is to deliver a flow regime that more closely mimics the natural water level fluctuations, with the expectation that native plant and animal communities will benefit (SFWMD, 2013).

Understanding the occurrence of apple snails relative to specific environmental conditions is essential because our study shows that land cover type does not have an effect on their occurrence; apple snails were found in all habitat types. In contrast, environmental conditions do have an effect on the abundance of apple snails and likely on the foraging success of Snail Kites. Identifying key habitat parameters such as these associated with kites and their dominant prey type can lead to water management regimes that sustain the endangered Snail Kite and the Florida apple snail.

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TABLES AND FIGURES

Table 1. **Total sites sampled with and without apple snails collected relative to land cover type, 2005-2012.** X^2 = 5.4, df = 5, P = 0.37. No snails were captured in 2013-2014, so these years were excluded.

Observed				**Expected**			
Land Cover Type	Number of Individual Sites with Collected Apple Snails	Number of Individual Sites Sampled without Apple Snails	Total Sites Sampled	Land Cover Type	Number of Individual Sites with Collected Apple Snails	Number of Individual Sites Sampled without Apple Snails	Total Sites Sampled
Slough	39	635	674	Slough	42	632	674
Prairies	3	63	66	Prairies	4	62	66
Trails	1	17	18	Trails	1	17	18
Holes	5	68	73	Holes	5	69	74
Solution Hole	5	23	28	Solution Hole	2	26	28
Other	1	16	17	Other	1	16	17
Total:	54	822	876	Total:	55	822	877

Table 2. **Total sites with apple snails collected relative to land cover type.** Compared among sites deemed suitable and unsuitable for Snail Kites based on the apple snail density threshold by Darby et al. (2012) (> 0.1–0.2 snails/m^2), 2005-2012. X^2 = 6, df = 5 P = 0.31. No snails were captured in 2013-2014, so these years were excluded.

Observed				**Expected**			
Land Cover Type	Sites Suitable for Kites	Sites Unsuitable for Kites	Total Sites with Apple Snails Collected	Land Cover Type	Sites Suitable for Kites	Sites Unsuitable for Kites	Total Sites with Apple Snails Collected
Slough	7	32	39	Slough	6.5	32.5	39
Prairies	0	3	3	Prairies	0.5	2.5	3
Trails	1	0	1	Trails	0.2	0.8	1
Holes	0	5	5	Holes	0.8	4	4.8
Solution Hole	1	4	5	Solution Hole	0.8	4	4.8
Other	0	1	1	Other	0.2	0.8	1
Total:	9	45	54	Total:	9	44.6	53.6

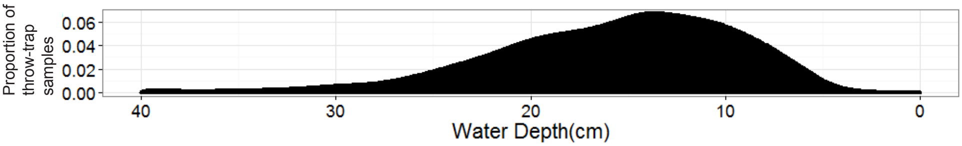

Figure 1. **Proportion of throw-trap samples collected relative to water depth 2005-2014.** The majority of throw-trap samples taken when water levels are ~5-28 cm (source Gawlik, unpublished data).

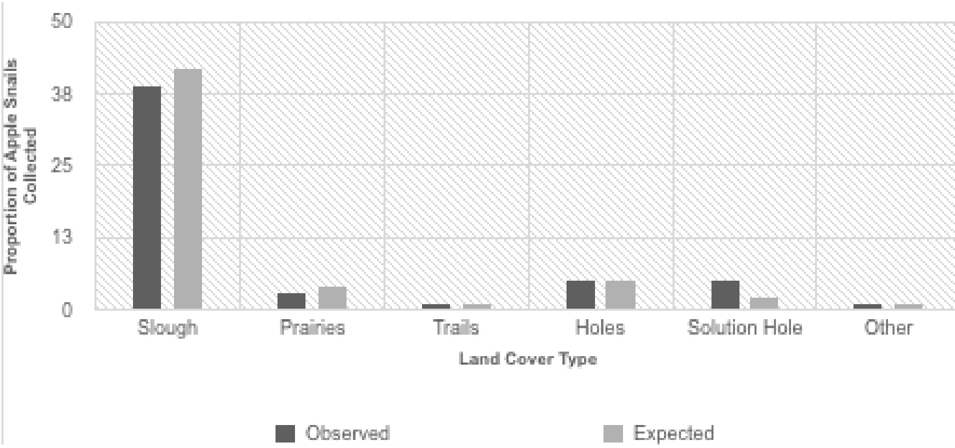

Figure 2. **Proportion of apple snails collected relative to land cover type, 2005-2012; observed and expected values (calculated in order to compare in a chi-square test of independence).**

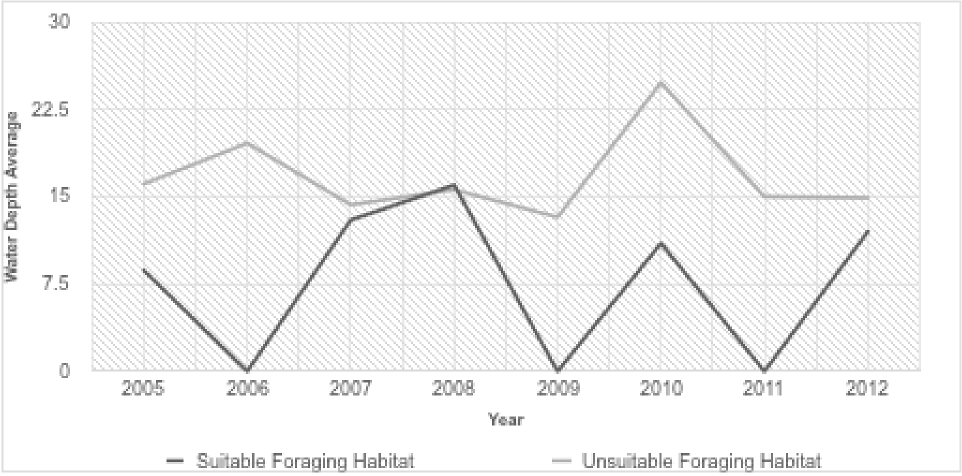

Figure 3. **Mean annual water depth at sites considered to be suitable (> 0.1–0.2 snails/ m^2, Darby et al.** [2012]), and unsuitable (apple snails collected; density threshold not met) foraging habitat for Snail Kites based on apple snail density.

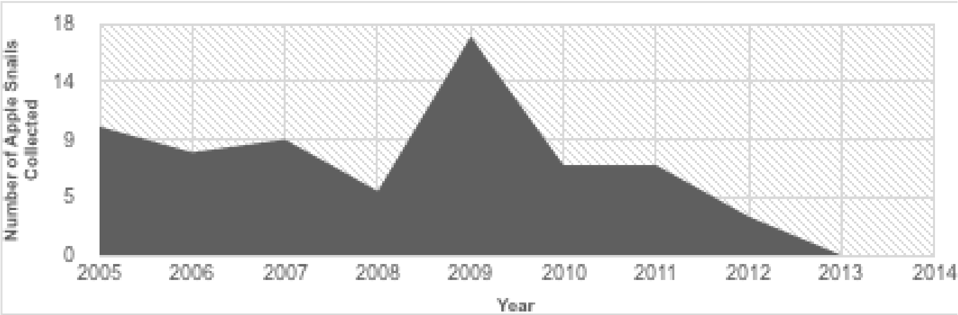

Figure 4. **Total number of apple snails collected by year, 2005-2014.**

Figure 5. **Number of sites where apple snails were detected each year, 2005–2014.**