

RESEARCH NOTE

THE PRESENCE OF AN EXOTIC SNAIL, *POMACEA MACULATA*, INHIBITS GROWTH OF JUVENILE FLORIDA APPLE SNAILS, *POMACEA PALUDOSA*

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The Florida apple snail, *Pomacea paludosa* (Say, 1829), is the only native *Pomacea* species in North America. Due to alterations in wetland hydrologic conditions, populations have been declining for several years (Darby, Bennetts & Percival, 2008). This reduction has had a negative impact on the federally endangered snail kite, *Rostrhamus sociabilis*, which feed predominately on apple snails (Stevens *et al.*, 2002). Snail kite populations have declined from 3,000 individuals in 1998 to less than 1,000 in 2011 (Reichert *et al.*, 2011). Wetland loss, climatic events and decreasing densities of native snails throughout south Florida have all probably contributed to this decline (Darby *et al.*, 2004; Darby, Karunaratne, & Bennetts, 2005; Karunaratne, Darby & Bennetts, 2006; Cattau *et al.*, 2009).

The presence of an exotic apple snail, *Pomacea maculata* (Perry, 1810) [previously called *Pomacea insularum* (d'Orbigny, 1839)], has also caused concern for the kite populations in Florida (Darby, Mellow & Watford, 2007; Desa, 2008; Cattau, Martin & Kitchens, 2010). Native to South America, its invasion has impacted rice and other crops worldwide and it has quickly spread throughout Florida (Hayes *et al.* 2012; Horgan, Stuart & Kudavidanage, 2012). Because exotic *Pomacea* are voracious feeders, have a longer lifespan and are highly fecund, they have the potential to cause harm to aquatic ecosystems and to threaten native apple snail populations (Barnes *et al.*, 2008; Hayes *et al.*, 2008).

Research examining the effects of exotic apple snails has typically focused on their impacts on macrophytes (Boland *et al.*, 2008; Baker, Zimmanck & Baker, 2010; Burks, Henley & Kyle, 2011) and not on their interactions with native snail species. One laboratory study documented negative interactions between *P. paludosa* and *P. maculata* in the form of decreased growth rates in the native snails (Conner, Pomory & Darby, 2008); however, this research was only conducted with adult exotic snails. The objective of this study was to investigate the effect of juvenile exotic snails, *P. maculata*, on the growth and survival of juvenile native snails, *P. paludosa*. Understanding their interactions will allow biologists and resource managers to make important decisions regarding Florida apple snail conservation and snail kite management, particularly in areas where exotic snails are present.

In July 2011, 10 *P. maculata* egg clutches were collected from a drainage canal in Indian River County, Florida and 30 native snail egg clutches were collected from the Fort Drum Wildlife

Management Area, Florida. Eggs from both species were allowed to hatch naturally in the laboratory, and hatching occurred within 1–2 weeks of collection. Once hatched, shell length (SL, from tip of the shell to the longest diagonal point on the lip at the aperture) was measured to the nearest 0.01 mm with digital calipers (García-Ulloa & Gallo-García, 2008; Garr *et al.*, 2011). Snails were randomly selected and stocked into one of five treatment ratios with four replicates each: 30 natives (30N:0E), 30 exotics (0N:30E), 15 natives:15 exotics (15N:15E), 24 natives:6 exotics (24N:6E), or 6 natives:24 exotics (6N:24E).

The experiment was conducted from July to September 2011 in an apple-snail culture facility at Florida Atlantic University's Harbor Branch Oceanographic Institute (FAU-HBOI). For the first month of growth, the groups of 30 snails were cultured in 20 seven-gallon (27-l) bow-fronted aquariums at a density of 75 snails/m² (30 snails/aquarium) (Garr *et al.*, 2011). After that time, snails were transferred to individual cylindrical tanks (75 l) and kept in their respective treatments to provide a larger water volume for their growth (100 snails/m²) (Garr *et al.*, 2012; Posch *et al.*, 2012). The aquariums, tanks and filters were cleaned biweekly to remove excess waste and slime, and photoperiod was set at 14L:10D (Garr *et al.*, 2011). Snails were fed a commercial catfish sinking pellet to satiation every day (c. 0.14 g/snail/d) (Garr *et al.*, 2011). Temperature was monitored twice per week ($n = 20$, $30.8 \pm 1.1^\circ\text{C}$), and ammonia (0.03 ± 0.02 mg/l), alkalinity (151 ± 10.9 mg/l) and hardness (169 ± 12.4 mg/l) were checked every other week ($n = 7$). All parameters remained within the optimal range for both species during the experiment (Hanning, 1979; Ramakrishnan, 2007; Garr *et al.*, 2011).

Final SL was measured at the end of the study and results are reported as mean weekly growth rate. An ANOVA was used to determine among treatment differences ($P < 0.05$) in mean weekly growth rates and survival of both species, followed by a Tukey's multiple comparison test for differences between treatments (SAS, v. 9.2; SAS, Cary, NC, USA). Data were tested for homogeneity of variances (Levene's test) and normality of distribution (Shapiro-Wilk test) and transformed if necessary.

Neither native (mean \pm SD = 3.67 ± 0.13 mm, $F_{3,12} = 1.60$, $P = 0.2418$) nor exotic snails (1.54 ± 0.06 mm, $F_{3,12} = 3.31$, $P = 0.0574$) exhibited significantly different initial shell lengths among snails assigned to the different treatments. However, overall growth rates (mm/week) among treatments differed for

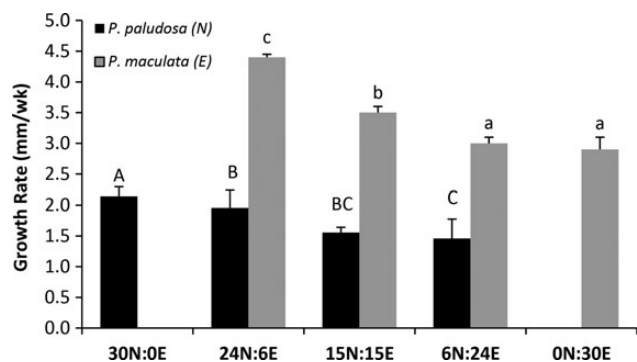


Figure 1. Overall growth rates (mean \pm SD, mm/week, $n = 4$) of juvenile native snails, *Pomacea paludosa*, and juvenile exotic snails, *P. maculata*, stocked at five different ratios (native: exotic, N:E) over a 3-month period. Significant pairwise differences are denoted by letters.

both the native snails ($F_{3,12} = 7.97$, $P = 0.0034$) and the exotic snails ($F_{3,12} = 137.24$, $P < 0.0001$) (Fig. 1). In treatments with an increased ratio of exotic snails, native snail growth rates ranged from 1.5 to 2.0 mm/week and were lower than those of the treatment with no exotics (30N:0E, 2.1 ± 0.15 mm/week). In contrast, exotic snail growth rates increased as the ratio of native snails increased (from 2.9 ± 0.2 mm/week for 0N:30E to 4.4 ± 0.05 mm/week for 24N:6E). Survival remained above 85% for all but one replicate within the treatments and no differences in total mean percent survival between native snail treatments ($F_{3,12} = 0.86$, $P = 0.4902$) or exotic snail treatments ($F_{3,12} = 0.89$, $P = 0.4725$) were detected.

Increased presence of *P. maculata* resulted in lower growth rates in native snails, especially in treatments where exotic snails were dominant. Suppressed growth has also been recorded when juvenile native snails were stocked with adult *P. maculata* at varying densities (Conner *et al.*, 2008). These results suggest that native snails may be susceptible to interspecific competition with the exotics, as has been demonstrated before with other snail species (Riley, Dybdahl & Hall, 2008). It is thought that enhanced feeding rates and higher conversion efficiencies may give the exotic *Pomacea* snails a competitive edge (Morrison & Hay, 2011). In our study, it is unknown whether or not the exotic snails consumed a greater proportion of the food. However, there is currently no evidence that *P. maculata* is displacing *P. paludosa* through resource competition (Pomacea Project, Inc., 2013).

A SL of more than 25 mm has been considered indicative of sexual maturity in *P. paludosa* (Hanning, 1979). The native snails in those treatments in which they were exposed to numbers of exotic ones equal or greater than their own did not reach this size threshold in 3 months (SL: 21.8 ± 1.0 mm and 21.1 ± 3.7 mm, respectively). It is likely that a decreased growth rate of native apple snails in the wild could contribute to lower survival during the overwintering period, to a higher susceptibility to predation and to a delay in the onset of sexual maturity (Darby *et al.*, 2008). This could also lead to variable size and age at first copulation (Snyder & Snyder, 1971; Hanning, 1979; Tanaka *et al.*, 1999; Estoy *et al.*, 2002) and an increased chance that females would produce smaller eggs and lay clutches less frequently (Williamson, Cameron & Carter, 1976; Tanaka *et al.*, 1999). Ultimately this could have an effect on recruitment for the following year (Tanaka *et al.*, 1999), as has occurred in other snail populations (Lam, 1994).

In our study, exotic snails had increased growth rates in the presence of more native snails; a facilitation effect that has been observed in another pair of exotic-native snails (Riley *et al.*, 2008). Even though our experiment was not explicitly designed to test the mechanism, an alleviation of intraspecific competition

in *P. maculata* could also explain our results. Growth rates in treatments with the highest exotic densities (0N:30E and 6N:24E) were not significantly different. Density-dependent growth of snails in captivity, whether due to resource competition, mucous secretions or cannibalism, has been well documented (Williamson *et al.*, 1976; Hanning, 1979; Perry & Arthur, 1991; Estebenet & Cazzaniga, 1992; Estebenet & Martín, 2002; Carlsson & Bronmark, 2006; Garr *et al.*, 2011).

Densities of *P. maculata* (>20 mm SL) in Florida wetlands range from 0.2 to 5 snails/m² and it has now become the dominant snail species in some areas (Darby, 2006; Pomacea Project, Inc., 2013). Numerous methods have been tried to eradicate exotic snails. However, methods such as pesticides (e.g. copper sulphate), biological control agents (e.g. fish and crustaceans) and a range of mechanical control measures (e.g. physical removal of snails and eggs) have not been proven successful or practical (Barker & Watts, 2002). Studying the interactions between native and exotic apple snails may help us to gain a better understanding of how to manage exotic *Pomacea* species, further prevent their spread to areas where native snails are found, and inform protocols for native snail restoration programs.

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