Is Environmental Calcium Availability Limiting Dispersal of an Invasive Snail in Lake Seminole and Associated Smaller Lakes?

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Abstract. Since its introduction to the United States from South America in the late 1980s, the spread of the Giant Apple Snail (*Pomacea maculata*) is of widespread interest because of its ability to affect ecosystem processes. Physicochemical parameters, such as pH and minimum annual winter temperature, have been used to predict spatial limits of *P. maculata* dispersal, indicating much of the southeastern US to be suitable habitat. In Lake Seminole, *P. maculata* was first documented in 2008, and the dispersal within the lake has been surveyed in 2013 and 2014. Availability of calcium may influence gastropod distribution, and calcium in Lake Seminole varies from areas of high groundwater input to isolated wetlands adjacent to the lake that receive surface runoff and rainfall, and exhibit much lower calcium concentrations. These isolated wetlands may not fit the ecological requirements of the snail, and may not be at risk of future dispersal of invasive snails.

INTRODUCTION

Snails of the family Ampullaridae include several globally successful invaders of aquatic habitats. In the southeastern US, the introduction, establishment and spread of *Pomacea maculata* has been documented across lakes, reservoirs, wetlands and rivers, but the ecosystem alterations as a result are still poorly understood.

First introduced in Florida in the late 1980s, *P. maculata* could adversely affect endangered Snail Kite populations, which primarily prey on native *P. paludosa* (Darby et al. 2006). *P. maculata* dispersal and predicted range expansion has been broadly studied in an attempt to be responsive to its introduction in new ecosystems (Ramakhrishnan 2007, Byers et al. 2013).

Of the environmental, physical and climate factors significant to predict suitable habitat of *P. maculata* (water temperature and pH), calcium availability has yet to be related to the spread of *P. maculata*. Calcium, needed in shell creation and previously studied in gastropod distributions (Walsh 2001; Rundle et al. 2004), can be available in several environmental forms (dissolved, particulate, organism tissue) but is dependent on the inherent availability within an ecosystem (Walsh 2001).

In the Coastal Plain of southwestern Georgia and much of Florida, connectivity to the Upper Floridan Aquifer provides calcium-rich groundwater to many of the lakes and rivers (Torak et al. 2005). However, this same geology causes terrestrial depressions, which can fill over time with calcium-poor surface runoff and precipitation to create hydrologically seasonal wetlands and ponds.

In the Lake Seminole, the last impoundment in the Apalachicola-Chattahoochee-Flint (ACF) basin, *P. maculata* was first observed in 2003, and has since dispersed within the lake[1]. The lake receives substantial groundwater from the Upper Floridan Aquifer, but as a result of the impounding of the lake, the groundwater potentiometric surface was raised, causing the formations of small ponds in the area directly around the lake. These ponds, which are located near the invasion front of *P. maculata* within the main body of Lake Seminole, are an ideal test area to monitor the effect of differing water chemistry (calcium availability, alkalinity, pH) on the spread and dispersal of a highly invasive snail.

METHODS

Study Sites

Lake Seminole is a 15,216-ha impoundment within the ACF watershed. The lake drains a total of 46,151 km^2

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[1] *http://www.sam.usace.army.mil/Portals/46/docs/recreation/OP-AC-WS/docs/2013_Seminole_Aquatics_Plan.pdf*

of western Georgia and eastern Alabama. The mean lake depth is 3 m and its maximum depth is 10.7 m. The lake has many native and non-native plants species, including submerged (*Hydrilla verticillata*, *Potamogeton illinoensis*), floating (*Eichhornia crassipes*), and emergent (*Zizaniopsis miliacea*) species, which may serve as food sources for invasive *P. maculata*. Previous studies have shown that the abundance of invasive *Hydrilla* can significantly affect the nutrient processing and loading within – and transported from – the lake (McEntire 2009; Shivers 2010)

Located between the Flint River and Spring Creek arms of Lake Seminole are the Silver Lake and Lake Seminole Wildlife Management Areas (WMAs), which comprise a total of 4,516 ha. Within the WMAs are six accessible ponds that were once depressional wetlands that are perennially filled as a result of the lake impoundment. Connecting the Flint River to Spring Creek are wetted channels open to boat access, which create a gradient between the groundwater-rich lake and surface-water runoff from the WMAs.

Egg mass surveys

Presence and distribution of invasive and native *Pomacea* in Lake Seminole were monitored in a full-lake shoreline survey using presence of egg masses in July 2013 and July 2014. *Pomacea sp.* can be best identified to species by the color and size of egg masses (Hayes et al. 2012), which are deposited on emergent surfaces (vegetation, sea-walls, boat docks, tree roots etc.) in the littoral zones of lakes, rivers and wetlands. Using a guide provided online from Florida Fish and Wildlife Conservation Commission[2], we identified two species of *Pomacea* across Lake Seminole. Egg masses were surveyed rather than adults because of their definitive species determination as proxy for presence of the species, and as a way to compare the reproductive output of each species across the lake.

In 2013, 97 predetermined survey locations, spaced every 1-km, on the Lake Seminole shoreline were identified using ArcMap 10.1, and at each of these predetermined locations, a 5-minute shoreline transect was completed by two observers. Egg masses were counted for each species observed at each location, and an average was taken between the two observers. In 2014, an additional seventy 1-km spaced survey locations in adjacent ponds, backwater channels and smaller drainages to Lake Seminole were surveyed.

Calcium and alkalinity determination

Quarterly, three 1-L grab samples were taken from upstream, in-lake and dam outflow sites across Lake Seminole and from nearby lakes in the Silver Lake WMA (Fig 1, inset). Samples were filtered over ashed 0.7μm GF/F prefilters (Millipore Ltd, Tullagreen, CO). Filtered samples were analyzed for calcium using a PerkinElmer AAnalyst 400 Atomic Absorption Spectrometer. Unfiltered aliquots were analyzed for alkalinity using a MettlerToledo DL15 titrator.

RESULTS

Pomacea presence in Lake Seminole

In Lake Seminole, native *P. paludosa* and invasive *P. maculata* were documented across the lake. Across the 98 sites, *P. maculata* were observed at 19 sites in 2013 and at 21 locations in 2014, primarily on the Flint River arm of the lake. *P. paludosa* were observed at 51 sites in 2013, and 55 sites in 2014. Among the additional 2014 survey locations, *P. maculata* were observed at four locations and *P. paludosa* were observed at 49 locations, predominately in Fish Pond Drain and Cypress Pond, which are smaller drainages to Lake Seminole located between Spring Creek and the Chattahoochee River (Fig 2, 2014).

P. maculata were observed on the Flint River and Spring Creek arms of Lake Seminole, and the average number of egg masses per site decreased from 73 in 2013 to 26 in 2014. *P. paludosa* were observed on all arms of the lake, but showed a similar decrease in average egg masses per site from 51 in 2013 to 38 in 2014. In the adjacent to the Silver Lake WMA, *P. maculata* were observed in the wetted channels connecting the Flint River and Spring Creek (mean egg masses = 22) in 2014, but no egg masses were observed in the ponds and lakes within SL WMA. Though not surveyed, *P. maculata* egg masses were not observed in these channels in 2013, but presence in 2014 suggest ongoing expansion of *P. maculata* range. *P. paludosa* were found across the survey range in both years, but no egg masses were observed in Silver Lake WMA ponds or wetted channels in 2014.

Calcium and alkalinity variability

Average calcium concentrations and alkalinity varied greatly across the lake (Table 1), with Spring Creek having the highest calcium and alkalinity (44.3 and 129.4 mg/L, respectively), while Silver Lake WMA ponds had the lowest amounts (4.6 and 19.3 mg/L, respectively).

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[2] *http://myfwc.com/media/673720/FWC_applesnails_FLMS_handout.pdf*

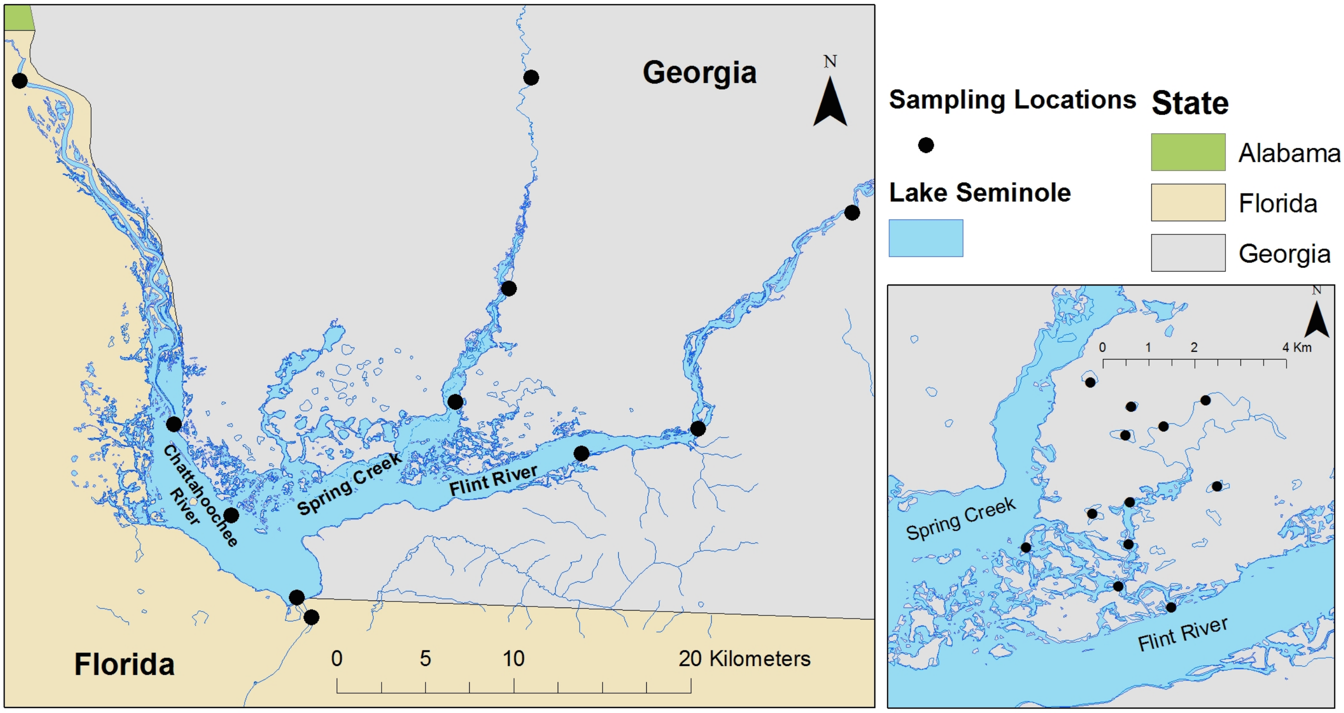

Figure 1: Calcium sampling locations in Lake Seminole, and Silver Lake WMA (inset), which is located between the Flint River to the south and Spring Creek to the west.

Table 1: Mean calcium, alkalinity, and specific conductance (Sp Cond) determined at sampling locations across Lake Seminole and in Silver Lake Wildlife Management Area (WMA).

Site	Calcium (mg/L)	Alkalinity (mg/L)	Sp Cond (μS/cm)
Flint River	18.9	59.8	145
Chattahoochee River	9.5	49.4	136
Spring Creek	44.3	129.4	249
Lake Seminole	20.8	68.9	166
WMA Ponds	4.6	19.3	48

DISCUSSION

Native and non-native Pomacea were found throughout Lake Seminole, and there is particular interest in how each species distribution will change over time. Non-native *P. maculata* were first documented in 2003 on the south shoreline of the Flint River arm of the lake, and have since dispersed from the introduction location (Shivers et al. In Review). *P. paludosa* has been recorded in the lower Flint River basin (Thompson 2004) but their historical distribution outside of the Everglades, FL, is limited.

Environmental calcium and carbonate alkalinity vary greatly in Lake Seminole, likely as a result of variability of mineralized groundwater input to the lake from the Upper Floridan aquifer to the Flint River, Chattahoochee River and Spring Creek (Torak et al. 2005). This variability may affect the survival of all gastropod and mollusk species with calcium carbonate shells, including non-native *P. maculata*, and influence where future satellite populations of non-native snails may successfully establish. Both species of Pomacea were observed in areas of the lake where dissolved $\text{Ca}^{2+} \geq 7.5$ mg/L and carbonate alkalinity ≥ 37.1 mg/L. Calcium variability may also affect the diversity and abundance of freshwater mussels and crayfish, which have been previously studied in the lower Flint River basin (Golladay et al. 2004; Atkinson et al. 2010).

Use of physical and climate variables have been used to predict the spatial limits of dispersal for *P. maculata* (Byers et al. 2013). Including environmental calcium as a parameter to incorporate into future predictions will better identify the spatial limits of dispersal, especially in the Coastal Plain of the southeastern US. However, *P. paludosa* have established populations in habitats with low calcium (Glass and Darby 2009). This may indicate a native species adaptation to reduced calcium availability in the Everglades, or overestimate the physiological cost to gastropod presence in low calcium environments. However, the calcium concentrations observed in the Glass and Darby (2009) study ($\text{Ca}^{2+} = 3.6$ mg/L) were lower

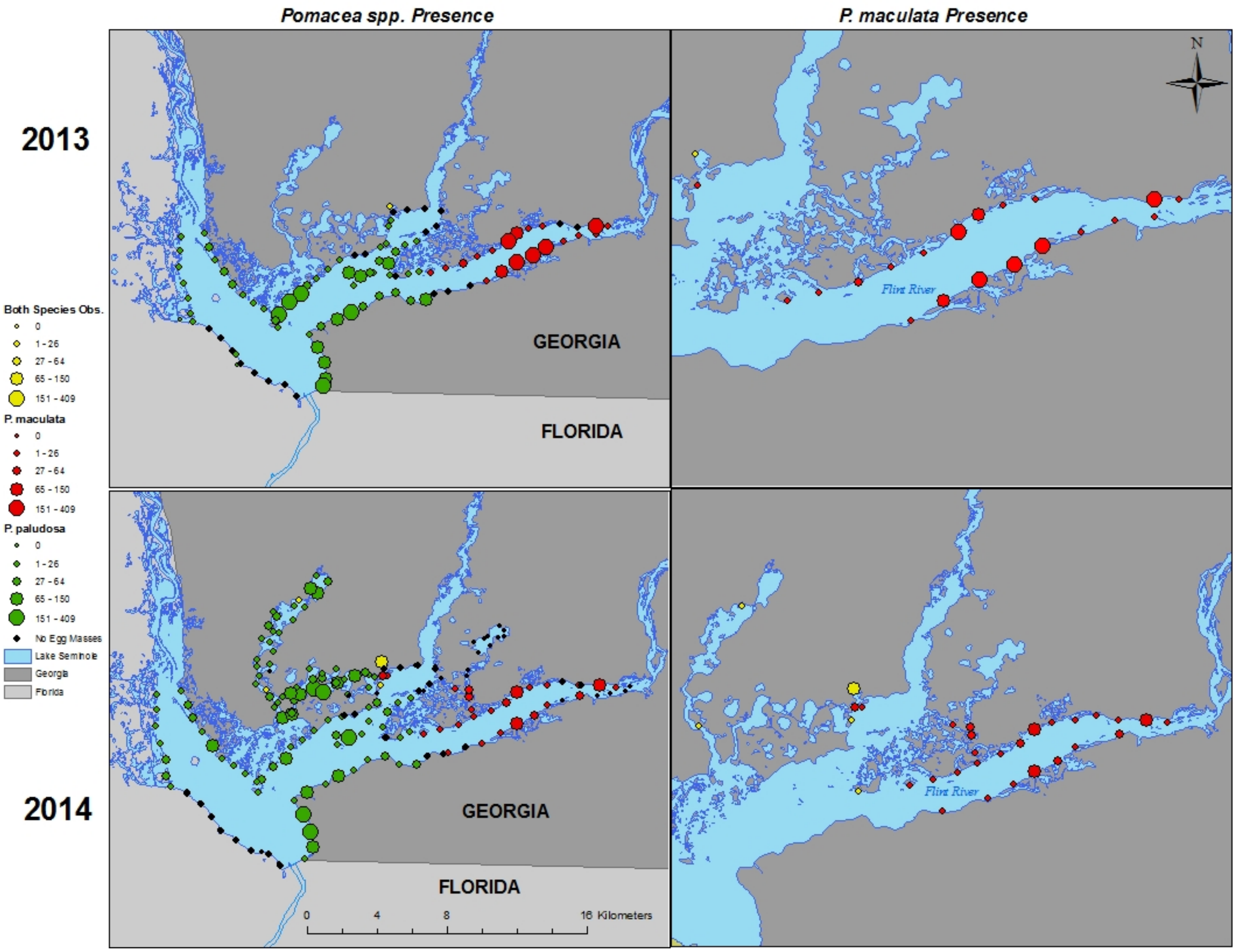

Figure 2: Completed egg mass surveys for 2013 (top) and 2014 (bottom) (left panels). Locations where invasive *P. maculata* were observed are shown to the maximum spatial extent in the right columns for 2013 (above). and 2014 (below). Green dots indicate *P. paludosa* egg masses observed, and red dots represent *P. maculata* egg masses observed. Yellow dots represent locations with both species observed. Black dots indicate where neither observed.

than what was observed in the main body of Lake Seminole ($Ca^{2+} = 21.0$ mg/L), but are similar in concentration to what is observed in the isolated ponds of Silver Lake and Lake Seminole WMAs ($Ca^{2+} = 4.6$ mg/L).

Using this study as a guide, calcium concentrations in the Silver Lake WMA ponds may not meet the environmental calcium requirement of *Pomacea spp.*, and be less suitable in the dispersal of *P. maculata* and explain the absence of native *P. paludosa*.

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