THE MYSTERY OF THE CHINESE MYSTERY SNAIL: ECOLOGICAL IMPACTS OF AN INVADER

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INTRODUCTION

As more and more nonnative invasive species become established across the world, it becomes important to set priorities for management of these species. As natural resource managers neither have the time nor money to control all invasive species, they need to know which species to control and which to leave alone. Byers et al. (2002) detailed directives by which to direct research of invasive species. They stated that one of the prime routes to obtain knowledge for prioritizing invasives is to study the impacts of nonnative species on native communities. Parker et al. (1999) quantified the impacts of an invader with the general equation:

Impact = Range x Abundance x Effect

While range and abundance may be relatively easy to define, how do we quantify the effects of an invader? Parker et al. (1999) went on to list five general categories of effects: effects on individuals, genetic effects, population dynamic effects, community effects, and effects on ecosystem processes. If we are to set priorities for management of invasives, we must know if the species is having a large impact on native ecosystems or if it is a malign invader. This study seeks to determine the impacts of the Chinese Mystery Snail (*Bellamya chinensis*) and to determine whether it should be considered a serious threat to native species and ecosystems.

Chinese mystery snail

The Chinese Mystery Snail is the common name of an Asian freshwater prosobranch snail, *Bellamya chinensis*. *B. chinensis* is native to several Asian countries including Asiatic Russia in the Amur Region, Myanmar, China, Japan, Indonesia, Korea, the Philippines, Vietnam, and Thailand (Pace 1973). This snail was only recently placed into the genus *Bellamya* by Smith (2000) and has several other scientific names in the older literature: *Viviparus chinensis malleatus*, *Viviparus japonicus*, *Viviparus stelmaphora*, *Paludina malleata*, *Paludina japonicus*, *Cipangopaludina malleata*, and *Viviparus malleatus* (DNR 2005).

Bellamya chinensis was originally introduced into the United States in the early 1890s through the Asian food markets in San Francisco, California (Wood 1892). The species was later sold through the aquarium trade and marketed for use in aquaria and landscaping ponds because of its ability to clear up water and lack of feeding upon vegetation. The species is now found in 37 U.S. states and four Canadian provinces, most predominately in the northeastern U.S. (Jokinen 1982). Its patchy distribution suggests that it was spread from aquaria release into local waters (Figure 1).

B. chinensis is a benthic grazer and filter-feeder, feeding primarily on benthic and epiphytic diatoms (Plinski et al. 1977). This species is typically found on sandy to muddy substrates (Clench and Fuller 1965) in slow-moving waters such as lakes, pond, rice paddies, irrigation canals, roadside ditches, and slow-moving streams (Pace 1973). Pradshad (1928) has documented this species in depths reaching from the shoreline up to 20m depth. These snails are the second largest snails in North America, with some individuals reaching lengths of 6.5 cm (Clench and Fuller 1965). Stanczykowska (1971) found that despite its large size, *B. chinensis* can be found at densities of up to 25 individuals/m^2 with a shell-free dry biomass of 25 g/m^2. Despite the ability of *B. chinensis* to spread across North America, Jokinen (1982) has shown that *B. chinensis* is only found in waters with more than 5ppm calcium, indicating that the snails may not be able to grow in very soft waters.

The lifespan of *B. chinensis* is typically four to five years (Jokinen 1982). During spring and summer, 100% of females are carrying embryos. Females produce a minimum of 169 embryos (Stanczykowska *et al.* 1971) and can carry up to 102 at one time (Crabb 1929). The young are born from June through October (Stanczykowska et al. 1971). In October, the snails begin to migrate to deeper water where they remain for winter.

As this species is spread widely across North America and is often abundant, it could have a large ecological impact on native species and ecosystems. This study seeks to determine if *Bellamya chinensis* is having an impact on native species and ecosystems, possibly through behavioral interactions, filtering, excretion, ingestion, and/or interspecific competition.

Methods

To assess the abundance of *B. chinensis*, I measured field densities, made a length to biomass conversion, and then calculated an estimate of field biomass. I then studied some specific mechanisms of interaction of *B. chinensis* with our ecosystems by assessing behavioral interactions with other snail species, monitoring ingestion and determining filtering rates. Finally, to determine whether the presence and activities of *B. chinensis* have an impact on our ecosystems, I set up a microcosm experiment in which I monitored phytoplankton, nutrient levels, and relative growth rates of other common snail species in the presence of *B. chinensis*.

Site description

Field density measurements and collections of snails were made at the Basher Kill Marsh, a 1,214 hectare marsh. The marsh is located in the Basher Kill Wildlife Management Area in southeastern New York State. The Basher Kill Marsh is fed by the Basher Kill (drainage basin of 189 km^2), a tributary of the Neversink River.

Field measurements

Ambient densities of *B. chinensis* were determined with 0.25 m^2 quadrats in three different habitats at three shoreline sites within the marsh: a boat landing, the marsh outlet, and a bridge that crossed the middle of the marsh (Figure 2). Five density measurements in open water were taken at each of the three sites. Five density measurements in aquatic vegetation edge habitat were taken at both the bridge and boat landing sites. Five density measurements in heavily vegetated habitat were taken at the boat landing site. The quadrats were searched tactilely, and all *B. chinensis* were collected from the 30 quadrats. Snail shell length was measured with a ruler. The snails were transported back to the lab in coolers filled with wet paper towels. In the lab, the snails were stored overnight in a refrigerator.

Length to biomass conversion

To use length as a way to estimate shell-free dry biomass, I had to calculate a conversion factor. To do this, I selected 54 snails of various sizes from my aquaria (see Behavioral observations below) as these snails should be most fully fed and similar to their natural conditions. I measured shell length, froze the snails, thawed them, removed the shell contents, and dried the shell contents for several days. Shell-free dry biomass was then regressed against shell length (Figure 3).

Estimation of field biomass

To estimate field shell-free dry biomass of *B. chinensis* per square meter, I used the average field shell length and the weight to length conversion to estimate average field shell-free dry biomass. I then multiplied this biomass by the average field density.

Behavioral observations

To observe the behavior of *B. chinensis* and its interactions with other snail species, I set up nine 37.9 liter aerated aquaria in a climate-controlled room kept at 22^oC ($\pm 1^oC$). I divided the aquaria into three groups of three and kept each group under four fluorescent light tubes with a 14:10 hour light-dark regime. I filled the aquaria with benthic sediments and water samples collected from a local pond. I changed one third of the water in each aquarium weekly. The aquaria were allowed to stabilize for a week before introducing the snails. I monitored the movement, behavior, and interactions between *B. chinensis*, *Stagnicola elodes*, and *Helisoma trivolvis*. Of special interest was what happens when *B. chinensis* encounters another species. I monitored whether *B. chinensis* avoids the other species or runs into it. I also monitored the effects of encounters upon other species (i.e. whether an encounter caused the snails to stop moving or feeding).

Ingestion

To determine the ingestion rates of *B. chinensis*, I used 35 randomly selected snails from my aquaria. Snail shell length was measured and used to estimate shell-free dry biomass. Each snail was placed in a plastic bowl filled with its own aquarium water and allowed to sit for 30 minutes. After 30 min, the snails were removed and the pellet-like excrement (with small amounts of water) was collected with an eye dropper. Four aquarium water samples were used as a control to account for non-excrement suspended materials. The excrement and water were then dried overnight and weighed. The average control dried sample weight was subtracted from the snail excrement sample weights. If a snail excrement sample was calculated to be a negative weight, I converted it into a zero as a negative excretion weight is nonsensical (this occurred for three samples). I then estimated ingestion rates by using a 30% assimilation rate of benthic grazers eating primarily diatoms and algae according to Hall et al. (2001) and used 46.8% percent activity per day according to Hutchison (1947) as *B. chinensis* eats continually when active. Ingestion rates per day were then modeled against estimated shell-free dry biomass (Figure 4). To estimate field ingestion rates per day, I used the average field shell length to estimate biomass, used this to estimate average field ingestion of the average snail, and multiplied this by the average field density.

Filtering

To determine filtration rates of adult B. chinensis, I set up nine tubs filled with fresh pond water. The snails were allowed to acclimate to the pond water in a separate container for one hour before the experiment was started. Each tub was filled with 8 L of water. Five adult snails (>4 cm in length) were added to each of six tubs, while three tubs were used as controls (no snails). Snails that kept their shells closed were removed from the experiment. Water samples were taken before the snails were added and two hours later. The water samples were filtered through GF/F filters and analyzed for chlorophyll a (Loftus and Carpenter 1971). The average loss of chl a in the control aquaria was subtracted from the experimental measurements in the tanks with snails. Filtration rates were calculated as in Roditi (1996):

$$\text{Filtration rate (L/h*snail)} = (\text{L of water}/\text{\# of snails})*[(\ln(\text{initial chl } a \text{ concentration}) - \ln(\text{final chl } a \text{ concentration}))/(\text{number of hours})]$$

To estimate field filtration rates, I used the average filtration rate per snail and then multiplied it by the average field density.

Competition Experiments

To determine the effects of different levels of densities of *Bellamya chinensis* upon other snail species, microcosms were set up in 568 L animal watering troughs (bottom surface area ~0.5 m^2, total internal surface area ~ 2m^2). These tanks had been filled with pond benthos, macrophytes, and snails and have been in position outdoors for years providing established communities. Before starting my experiment, I homogenized the tanks to reduce between-tank differences. All snails within the tanks were removed and sediments and water were intermixed between tanks. The tanks were allowed to stabilize for one week.

There were four species of snails previously inhabiting the tanks: *Bellamya chinensis*, *Stagnicola elodes*, *Helisoma trivolvis,* and *Physella* sp. All of the *B. chinensis* and *Physella* sp. snails were removed from the tanks. *S. elodes* and *H. trivolvis* were removed, grouped into three size categories, and equally divided among the tanks resulting in 47 *S. elodes* (~94 snails/m^2) and 51 *H. trivolvis* (~102 snails/m^2) per tank.

I then divided the tanks into three treatments of *B. chinensis* densities in triplicate. Three tanks were controls without *B. chinensis,* three were at low densities of *B. chinensis* (20 snails per tanks, ~40/m^2), and three were at high densities of *B. chinensis* (40 snails per tank, ~80/m^2). *B. chinensis* were divided into three size categories: small (<2cm), medium (2-4cm), and large (>4cm) and distributed between the tanks. These density levels were based upon field observations of low, medium, and high densities. Each tank was covered with deer fence netting to prevent predation and escape.

To monitor individual growth, I marked ten individuals of each species in each tank with different colors of nail polish. Shell length was measured with a calipers (± 0.015 mm) before and 5 weeks after the beginning of the experiment. Dead snails were replaced with similar sized snails within 3 days. Average relative growth rates were calculated as follows:

$$\textit{Average relative growth rate} = [\ln(\textit{length}_2)-\ln(\textit{length}_1)]/(\textit{time})$$

Average relative growth rate data were analyzed with a one-tailed linear regression.

To monitor the effects of *B. chinensis* on water quality and nutrient levels, I collected water samples weekly by taking ten subsamples from each tank and pooling them to obtain one sample per tank. The experiment was run for four weeks, however there were no time zero samples taken. Samples were analyzed for chl *a*, ammonia-nitrogen, nitrate-nitrogen, and phosphate-phosphorus. Chl *a* was analyzed with the methanol-fluorometery method (Loftus and Carpenter 1971). Ammonia-nitrogen, nitrate-nitrogen, and phosphate-phosphorus were analyzed with standard colormetric methods on a Latchet autoanalyzer (Latchett QuikChem 8000 Series FIA+). Chlorophyll and nutrient data were analyzed with a two-factor repeat measures ANOVA (Sigma Stat v. 3.00). Nutrient data were natural log transformed before analysis to fit normality requirements.

RESULTS

Density and biomass

The average population density of all of the sites was 31 ± 8 snails/m^2 (unless noted otherwise, all error terms are 1 SE). Densities ranged from 0 to 180 snails/m^2. The highest density levels were found in edge habitats with the lowest densities found in heavily vegetated areas (see Table 1). The average field shell length was 3.6 ± 0.1 cm. From my length to biomass study, I found that the shell-free dry biomass increased exponentially with shell length (Figure 3). Using this conversion, I estimate the average field shell-free dry biomass in the Basher Kill Marsh to be approximately 15 ± 4 g/m^2.

Specific methods of interaction

After over 6 hours of direct observation and additional hours of casual observation, I found that *B. chinensis* is in essence a "gentle giant." *B. chinensis* did not act aggressively toward other snail species. When *S. elodes* and *H. trivolvis* encountered *B. chinensis*, they did not exhibit any negative behavioral responses. Instead *S. elodes* and *H. trivolvis* continued to feed as they normally would, even if they were in direct contact with *B. chinensis*. I often observed *S. elodes* and *H. trivolvis* crawling on the shell of *B. chinensis*.

While *B. chinensis* may eat a relatively large amount of material per day, only a small part of their diet may come from filtration. *B. chinensis* ingests approximately one-half of its shell-free dry biomass per day (Figure 4), however these data were widely scattered, possibly due to variation in feeding activity. Using this approximation of ingestion rates, I estimate field ingestion rates to be approximately 9g/day*m^2. Filtration rates were extremely low; in fact three of the six calculated filtration rates were negative. The average filtration rate was 0.036 ± 0.061 L/snail*hour or 0.861 ± 1.46 L/snail*day. Despite the large variation, I estimate field filtration rates to be about 1 L/hour*m^2, or 20 L/day*m^2.

Microcosm experiment

Ammonium-nitrogen levels (Figure 5) were markedly different among the treatments (p=0.003), over time (p<0.001), and there was a significant treatment and time interaction (p=0.001). Nitrate-nitrogen levels (Figure 6) did not differ significantly among treatments (p=0.360), but there was a trend over time (p=0.006). However, there was no significant interaction between treatment and time (p=0.501). Phosphate-phosphorous levels (Figure 7) showed statistically significant differences among treatments (p=0.022) and a statistically significant trend over time (p<0.001), however there was no statistically significant treatment and time interaction (p=0.358). Phytoplankton levels (Figure 8) showed a significant time effect (p=0.001), but were not statistically different between density treatments (p=0.657), and there was no significant treatment and time interaction (p=0.439).

The presence of *B. chinensis* tended toward a statistically significant effect on relative growth rates of *S. elodes* and *H. trivolvis,* as well as itself (Figure 9). When comparing the control to the low and high density treatments together, there was a 30% decrease in growth rates of *H. trivolvis* (p=0.15) and a 62% decrease in *S. elodes* (p=0.06) while in the presence of *B. chinenesis*. There was also an 85% decrease in growth rates of *B. chinensis* between density treatments (p=0.007).

CONCLUSIONS

Because *B. chinensis* is widely distributed across North America and I have shown that they can occur at extremely high densities for such a large snail, their environmental effects are potentially severe. However, these effects do not appear to come through behavioral interaction with other snails. Behaviorally, these are fairly benign and gentle creatures. Other snails do not appear to act negatively while in the presence of *B. chinensis*. However, *B. chinensis* may be having behavioral impacts such as intimidation of other species that I did not observe.

Individual rates of filtration of *B. chinensis* appear to be very low to minimal. When we look at the population level effects upon phytoplankton levels in the competition experiment, phytoplankton decreased over the course of the summer, but these trends were not statistically significant. Perhaps longer studies could reveal that *B. chinensis* could indeed clear water columns. Some evidence that may indicate this fact is that upon initially observing the cattle watering tanks in there natural state before I started using them revealed that tanks with higher densities of *B. chinensis* were fairly clear while tanks without *B. chinensis* were rather cloudy and murky.
While filtration rates are relatively low, *B. chinensis* appears to ingest a rather large amount of food per day. When taking into consideration the large densities of *B. chinensis*, the field ingestion rates could be extreme. *B. chinensis* could be significantly limiting food resources of other benthic grazers.

While it appears that *B. chinensis* has an effect upon ammonium-nitrate concentrations, this effect is most likely due to snail deaths. In the beginning stages of the experiment, there was a higher rate of death than at the end of the experiment. This is reflected in the ammonium-nitrogen concentrations, high in the beginning and low in the end. So what becomes interesting is not the initial high concentrations of ammonium associated with snail death and decay, but the fact that there is relatively no difference between treatments when snail populations have stabilized. Another possibility for the large difference in ammonium concentrations could be excretion. The gradual decrease could then be explained by increased bacterial uptake. I also found no significant effect of *B. chinensis* densities upon nitrate-nitrogen concentrations.

While there are statistically significant differences in phosphate-phosphorus concentrations between tanks, the trends are not in an intuitive order. In fact, the control treatment has the highest concentration, followed by the high and then the low density treatments. The large variability in the control treatment concentrations is due to one especially high concentration tank. However, even when you remove this tank, the control treatment still has higher concentrations of phosphorus than the other treatments. Perhaps the tanks just started off with different concentrations of phosphorus, or perhaps *B. chinensis* is having some sort of unknown effect upon phosphorus concentrations.

While the relatively large decreases in growth rates of *S. elodes* and *H. trivolvis* were not significant, they were certainly close to the significance level. It is most likely that *B. chinensis* is lowering the growth rates of other snail species. It is also highly evident that *B. chinensis* heavily competes with itself. Perhaps a longer term study with more replicates could clearly reveal the effects of interspecific competition between *B. chinensis* and other snail species.

Overall, *B. chinensis* has little to no negative behavioral interactions with other snails, low filtration rates, minimal impacts on dissolved nutrient concentrations, large ingestion rates, and a competitive effect upon growth rates of other snails. So if we go back to the initial equation:

$$Impact = Range \times Abundance \times Effect$$

I find that while *B. chinensis* may have a relatively large range and can exist at high densities, it appears to have only minimal impacts on water quality and moderate to large negative impacts on other common snail species. Thus, I would have to conclude that *B. chinensis* has an overall moderate to severe impact on our native ecosystems and should be considered a serious threat to native ecosystems and snail species.

Future studies

Further study needs to be done on *B. chinensis* as I only studied a few short-term impacts of this animal. Studies should be focused towards long-term impacts on native snail populations, especially rare and endangered species. Studies should also seek to determine if this animal is an important host for parasite populations. This could be a special concern to the general public if *B. chinensis* could impact the abundance of swimmer's itch. Other effects could include bioturbation, effects on macroinvertebrate benthic grazers, and effects on predation of birds, fish and wildlife.

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APPENDIX

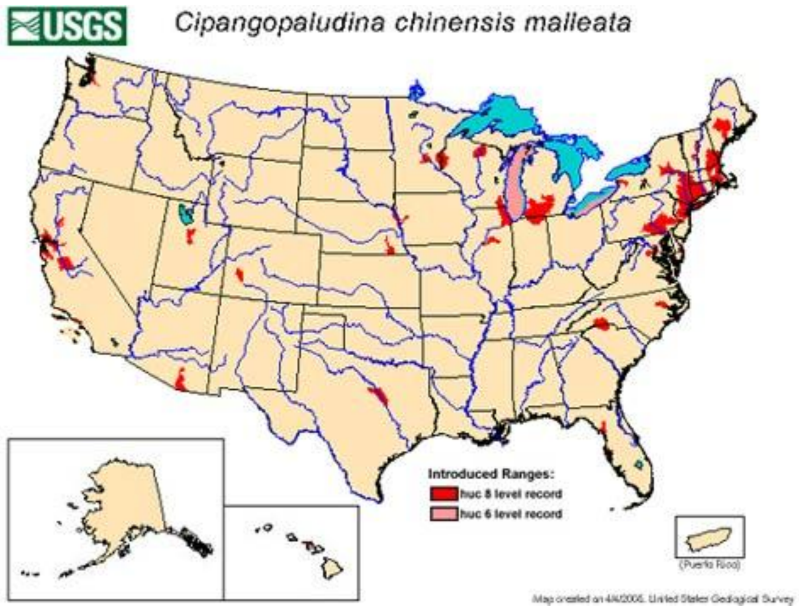

FIGURE 1. A map of the distribution of *B. chinensis* in the United States (Taken from Indiana Department of Natural Resources 2005).

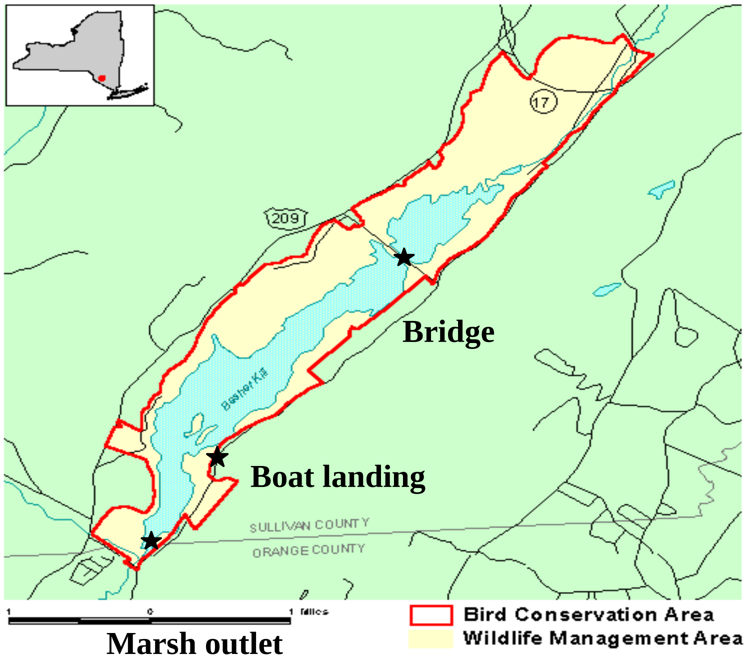

FIGURE 2. A map of the Basher Kill marsh. Stars (★) indicate field sites.

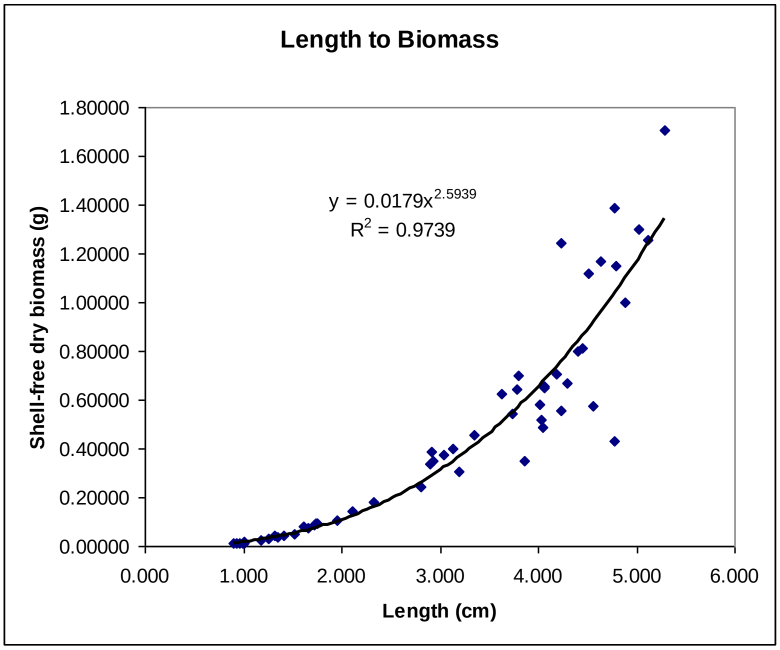

FIGURE 3. Regression of shell-free dry biomass against shell length of *Bellamya chinensis*.

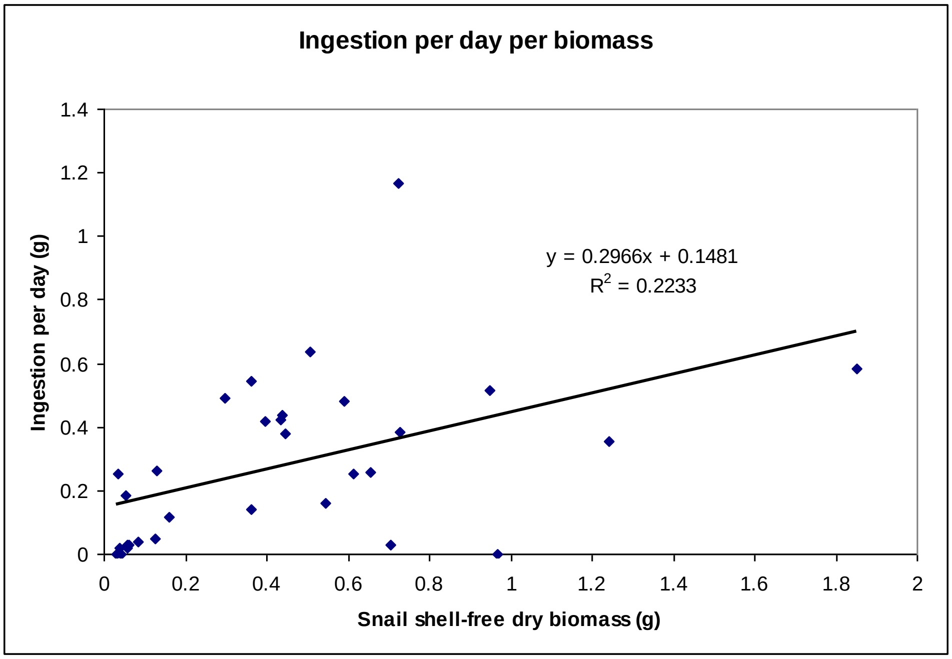

FIGURE 4. Snail ingestion per day modeled against shell-free dry biomass.

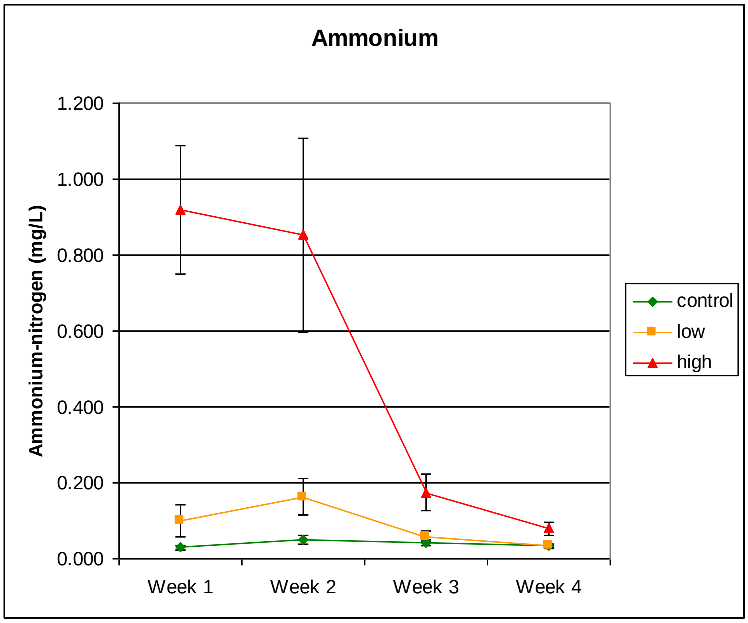

FIGURE 5. Ammonium-nitrogen concentrations over time. Error bars represent one standard error. Ammonium-nitrogen levels were markedly different among the treatments (p=0.003), over time (p<0.001), and there was a significant treatment and time interaction (p=0.001).

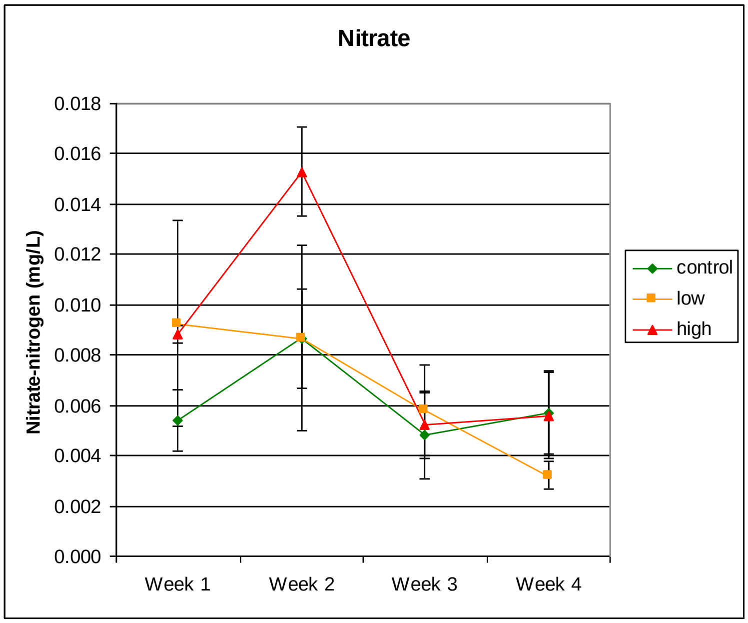

FIGURE 6. Nitrate-nitrogen concentrations over time. Error bars represent one standard error. Nitrate-nitrogen levels did not differ significantly among treatments (p=0.360), but there was a trend over time (p=0.006). However, there was no significant interaction between treatment and time (p=0.501).

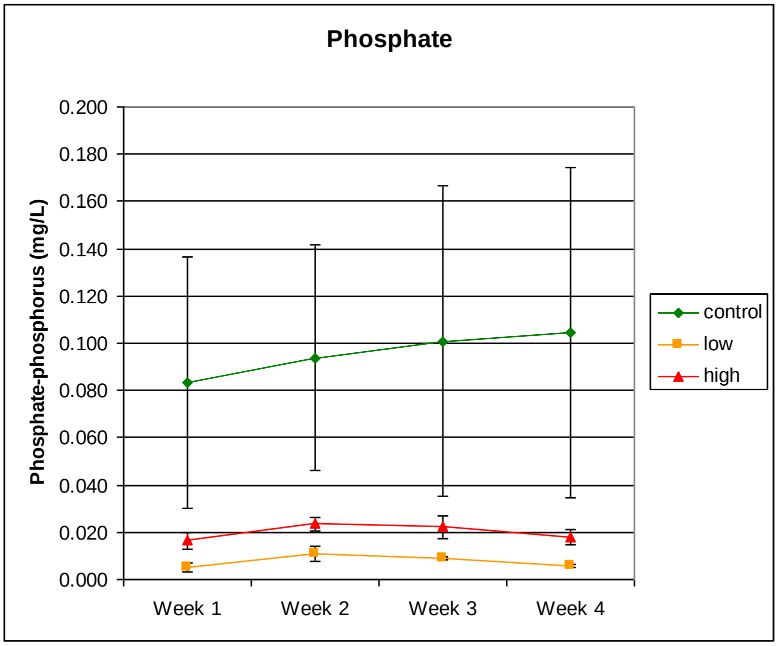

FIGURE 7. Phosphate-phosphorus concentrations over time. Error bars represent one standard error. Phosphate-phosphorous levels showed statistically significant differences among treatments (p=0.022) and a statistically significant trend over time (p<0.001), however there was no statistically significant treatment and time interaction (p=0.358).

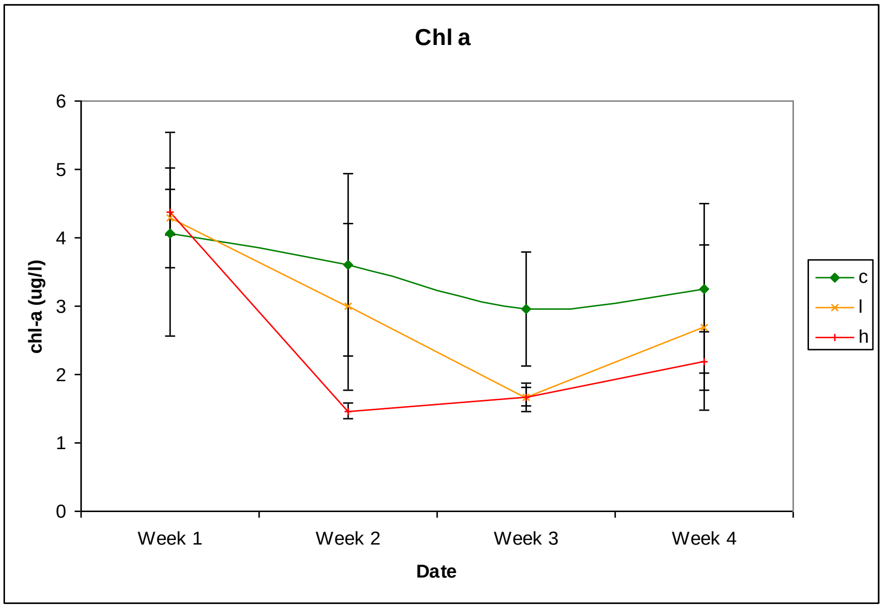

FIGURE 8. Chlorophyll *a* concentrations over time. Error bars represent one standard error. Phytoplankton levels showed a significant time effect (p=0.001), but were not statistically different between density treatments (p=0.657), and there was no significant treatment and time interaction (p=0.439).

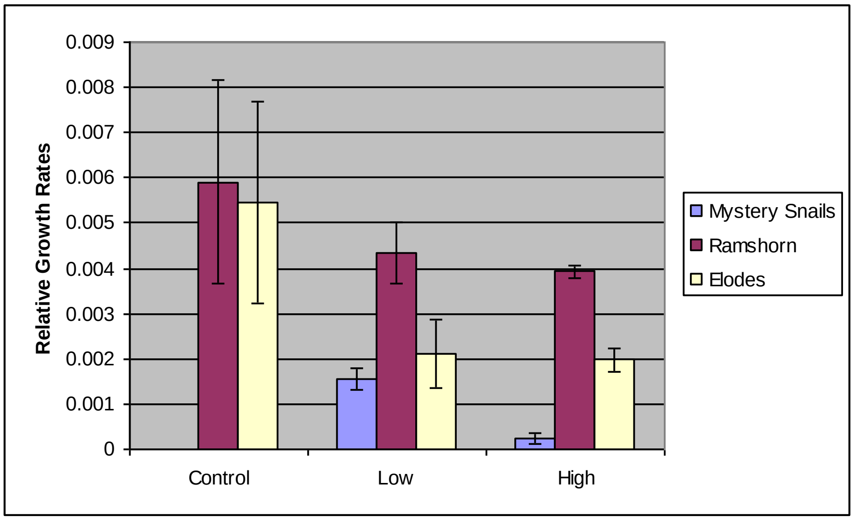

FIGURE 9. Relative growth rates of each snail species among various density treatments. Error bars represent one standard error. There was a 30% decrease in growth rates of *H. trivolvis* (p=0.15) and a 62% decrease in *S. elodes* (p=0.06) in the presence of *B. chinensis*. There was also an 85% decrease in growth rates of *B. chinensis* between density treatments (p=0.007).

TABLE 1. Field density measurements.

Habitat	**Minimum Density (snails/m^2)**	**Maximum Density (snails/m^2)**	**Average Density (snails/m^2 ± one standard error)**
Open water	0	120	21 ± 9
Vegetation edge	0	180	54 ± 18
Vegetation	4	36	15 ± 6