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Research Article

Survival and behavior of Chinese mystery snails (*Bellamya chinensis*) in response to simulated water body drawdowns and extended air exposure

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Abstract

Nonnative invasive mollusks degrade aquatic ecosystems and induce economic losses worldwide. Extended air exposure through water body drawdown is one management action used for control. In North America, the Chinese mystery snail (*Bellamya chinensis*) is an invasive aquatic snail with an expanding range, but eradication methods for this species are not well documented. We assessed the ability of *B. chinensis* to survive different durations of air exposure, and observed behavioral responses prior to, during, and following desiccation events. Individual *B. chinensis* specimens survived air exposure in a laboratory setting for > 9 weeks, and survivorship was greater among adults than juveniles. Several *B. chinensis* specimens responded to desiccation by sealing their opercula and/or burrowing in mud substrate. Our results indicate that drawdowns alone may not be an effective means of eliminating *B. chinensis*. This study lays the groundwork for future management research that may determine the effectiveness of drawdowns when combined with factors such as extreme temperatures, predation, or molluscicides.

Key words: aquatic; invasions; mollusk; management; drawdown; desiccation; nonnative

Introduction

Invasive species cause substantial economic and environmental damage (Pimentel et al. 2005) and threaten global biodiversity (Chornesky and Randall 2003). The negative effects of aquatic invasive species threaten the functioning and diversity of many freshwater ecosystems (Kolar and Lodge 2000 pp. 8–14 and 21–24). For example, zebra mussel [*Dreissena polymorpha* (Pallas, 1771)] invasions have harmed many aquatic systems (Strayer 2009). The Chinese mystery snail [*Bellamya chinensis* (Reeve, 1863) or *Cipangopaludina chinensis malleata* (Gray, 1834)] is another invasive mollusk with an expanding range in North America. Much remains unknown about the ecological impacts of *B. chinensis* invasions, but these snails have been documented to reach high densities (Solomon et al. 2010) and may even exceed the biomass of some fish species in invaded water bodies (Chaine et al. 2012). Although no significant adverse effects of *B. chinensis* invasions have been reported to date, the high fecundity of the species (Stephen et al. 2013) combined with its potential to alter aquatic ecosystems through competition with native snails (Johnson et al. 2009) warrants preemptive investigations of potential management actions aimed at its control.

Drawing down water bodies for extended periods is one method used to manage aquatic invasive species (Hovingh 2004; Cheng and LeClair 2011). Although drawdowns may not be feasible in most natural water bodies, it is a valid option for many commercially and recreationally important reservoirs. Drawdowns may result in mortality of aquatic species through desiccation or exposure to extreme temperatures (Tucker et al. 1997). *B. chinensis* is known to survive air exposure in mesic conditions for at least 4 weeks (Havel 2011), but little is known about their ability to survive in gradually drying substrate, or about their behavior in such conditions. In this study, we observed the response of *B. chinensis* to simulated water body drawdown events and prolonged air exposure. The study was primarily observational in nature, with the chief purpose of establishing a base of knowledge from which more in-depth studies of *B. chinensis* management can be developed.

Methods

Prior to the experiments, *B. chinensis* snails were obtained from local water bodies in Lancaster County, NE and acclimated to an aquarium for a minimum of 2 months. During the acclimation period, snails were able to feed on algae growing in the tank, but were also supplemented with boiled lettuce. The acclimation tanks and study containers were kept in a climate-controlled laboratory with room temperature water (18.9 °C) and low to moderate humidity (30–50%). We conducted two related experiments: 1) observations of the behavioral response of *B. chinensis* to 3 drawdown events in an aquarium; and 2) survival of snails during prolonged air exposure in separate containers.

Behavior experiment set–up and procedures

For the first experiment, 23 L of mud substrate obtained from a local recreational lake was placed in a standard 76-L aquarium and de–chlorinated tap water was added to obtain a total volume of 58 L of mud and water, which provided a 10–cm layer of water on top of a saturated 15–cm layer of mud. To simulate field conditions, the substrate was not sterilized and contained at least 2 native Nebraska snail species, *Physa gyrina* (Say, 1821), and *Helisoma trivolvis* (Say, 1817)*,* as well as blood worms (*Glycera spp.*) and other small, benthic invertebrates. Two *B. chinensis* snails were introduced from each of 5 size classes for a total of 10 snails (Table 1). *B. chinensis* length ranged from 7 to 50 mm. ACE Hardware brand Indoor/Outdoor Oil–based Enamel paint was used to mark snails with a letter to differentiate size classes, and a number to differentiate individuals within classes.

Table 1. Size of *Bellamya chinensis* used in aquarium drawdown experiments.

Size Class	Snail	Size (mm)
A	1	50
	2	48
B	1	33
	2	34
C	1	23
	2	21
D	1	14
	2	14
E	1	7
	2	7

Within the aquarium, we simulated 3 water body desiccation events: an evaporative drawdown, a gradual 5–day drawdown, and a rapid 5–hour drawdown. During the evaporative drawdown, water evaporated gradually from the aquarium over a period of weeks. In the 5–day drawdown, the water level was reduced by 2 cm once a day for 5 days. During the 5–hour drawdown, the water level was reduced by 2 cm each hour for 5 hours. For the 5–day and 5–hour drawdown events, a plastic pitcher was used to remove water above the 2–cm level. For water levels < 2 cm in depth, a turkey baster was used for water removal until the level reached the substrate surface. Substrate moisture content was not measured; however, before water was reintroduced, the substrate was observed to be highly fractured and completely dry on the surface. Snails were fed boiled lettuce and their behaviors were observed throughout each of the 3 aquarium drawdown events.

Survival experiment set–up and procedures

For the second experiment, we placed 8 native *P. gyrina* snails and 8 *B. chinensis* snails in each of 5 buckets. Four of the *B. chinensis* snails were juveniles (4 to 7 mm in length) and 4 were adults. The 4 adults in each bucket consisted of 4 different sizes ranging from 30 to 59 mm (Table 2). Buckets contained lake–bottom substrate, autoclaved to assure it contained no live *P. gyrina* snails that might be confused with the 8 *P. gyrina* snails that were part of the experiment. The substrate was 10 cm deep in each bucket with an additional 10 cm of de–chlorinated tap water atop the substrate.

Snails in each bucket were acclimated for 24 hours and were then subject to a rapid, 5–hour drawdown event, during which the water level

Table 2. Size of adult *Bellamya chinensis* in buckets and their fate after prolonged air exposure from 5 to 9 weeks after the drawdown.

Week 5		Week 6		Week 7		Week 8		Week 9	
Size (mm)	Fate	Size (mm)	Fate	Size (mm)	Fate	Size (mm)	Fate	Size (mm)	Fate
56	live	50	live	58	live	58	live	58	live
47	live	46	live	39	live	45	live	46	live
41	live	40	live	38	live	42	live	40	live
40	dead	29	dead	36	dead	35	live	34	dead

was lowered in 2–cm increments each hour for 5 hours, until all standing water was removed. The substrate in each bucket was then allowed to dry gradually through evaporation. Beginning 5 weeks after the rapid drawdowns, water was added to 1 bucket and snail survival was assessed. This was repeated each week until all 5 buckets had been checked, the last check occurring 9 weeks after the drawdown.

Results

Behavioral responses

During the evaporative drawdown experiment, we observed all *B. chinensis* snails to bury themselves partially or completely, only to reemerge again days later. In some instances, partially buried snails would leave portions of their foot, tentacles, or siphons protruding out of the mud, and the water near the siphons was observed to swirl. Four weeks after the initiation of the experiment, nearly all standing water had evaporated from the aquarium. At this point, all *B. chinensis* snails were partially to completely buried, and no further movement was observed. After an additional week without snail movement, we added de–chlorinated tap water to the aquarium to a depth of 10 cm. Within 15 minutes of inundation, some snails began emerging from their shells and the substrate. By the following day, 8 of the 10 snails were moving about the tank and feeding; the 2 smallest snails were lost.

After 2 weeks, the experiment was repeated with a 5–day drawdown, minus the smallest snail size class. The water level was drawn down in 2–cm increments once a day for 5 days. As water was removed on each of the first 3 days, snails crawling on the glass side of the aquarium near the water's surface were left exposed to the air. After approximately 3 to 5 minutes, exposed snails traveled down the glass until they were beneath the water's surface. In two incidents, rather than climbing down the wall, the snails stretched out of their shell, detached from the glass, and fell into the water. After drawing the water down to 4 cm on day 3, 5 of the larger snails sealed up and remained on the surface of the substrate. Three of the smaller snails continued movement as usual on either the glass wall or substrate. After the removal of all water, these snails withdrew into their shells and closed their opercula. After a week with no movement, water was reintroduced to the tank and all snails emerged from their shells alive.

B. chinensis were again observed on the glass sides of the aquarium at the beginning of the 5–hour drawdown experiment. The initial 2–cm removal left several of the snails exposed to the air, but all had moved down below the water surface within 15 minutes, much as they had done during the 5–day drawdown. Similar responses were observed during the second and third water removals. Following the fourth 2–cm water removal, several snails left the glass wall in favor of the mud substrate. The fifth 2–cm water removal eliminated nearly all standing water from the substrate surface. Within 3 hours, 6 of the snails had moved into a slight depression in the substrate where approximately 0.5 cm of water remained. Five of those snails moved back out of the depression over the next 3 hours and spread to different areas of the tank, some burrowing partially. By the following day, 7 of the snails were back in the depression, with one large snail buried elsewhere in the substrate. Four days after the drawdown, 5 snails were entirely buried and 3 were partially buried, with virtually no surface water remaining in the depression. No snail movement was observed for 4 weeks after the 5–hour drawdown, and water was added to the aquarium at the beginning of the fifth week. Three hours after the introduction of water, some snails began opening up and moving about the aquarium. Within 3 days, all 8 snails emerged alive.

Survival

Of the 20 adult *B. chinensis* snails monitored in buckets for 5 – 9 week desiccation periods, none completely buried themselves in the substrate. Three were partially buried, but the rest sealed their opercula and remained on the substrate surface. As water was reintroduced to 1 bucket each week, beginning at week 5, we observed that only one adult mystery snails in each bucket died, with the exception of the bucket where water was reintroduced after 8 weeks, in which all 4 adults survived (Table 2). All juvenile *B. chinensis* snails and all native snails in each of the buckets died.

Discussion

Our observations indicate that *B. chinensis* snails are capable of burying themselves relatively quickly in the mud substrate of lake bottoms and surviving prolonged periods of air exposure. Mud substrate may maintain moisture even without surface water, potentially increasing the ability of snails to survive desiccation events when buried. Although we documented quick burrowing ability, it did not always occur during drawdowns. This was particularly true for the survival experiment, in which only 3 out of 20 adult mystery snails partially buried. There are several potential explanations for this deviation. First, the shorter acclimation period of the survival experiment, compared with the 3 drawdown events, may have discouraged burying. However, many of the snails in the behavior experiment buried themselves at least once in the first 24 hours, so this may not be an adequate explanation. Second, the same snails were reused in each of the drawdown events of the behavior experiment, potentially making them accustomed to drawdowns and more apt to bury. As with the acclimation period explanation, however, this would not explain why these snails buried so quickly when initially placed on the mud substrate while the survival experiment snails did not. Third, soil autoclaving may have decreased burying by altering benthic invertebrate composition or other soil characteristics. Finally, the smaller surface area of the buckets in the survival experiment as compared to the aquarium in the behavior experiment may have influenced their behavior by crowding snails closer together.

Even when *B. chinensis* did not bury themselves during the survival experiment, by sealing their opercula and ceasing movement, adults survived 9 weeks without water or food. No juvenile *B. chinensis* survived 5 weeks of desiccation; this outcome may be related to their size, as Havel (2011) found smaller snails to be more sensitive to air exposure than larger snails.

In the behavior experiment, *B. chinensis* followed the water level as it receded, and once the water level had reached the substrate surface, they traversed the substrate and located a depression retaining water. Drawdowns of most water bodies could leave similar depressions of standing water in which exposed *B. chinensis* might concentrate. In these instances, snail elimination could be made more efficient by focusing on these areas with remaining water. Also during the behavior experiment, water was observed to swirl around the siphons of partially buried snails; more investigation is needed to determine if this is simply respiration, or a sign of filter–feeding.

Results of this study indicate that water body drawdowns by themselves may be an ineffective means of controlling *B. chinensis*. The duration of desiccation required to eliminate adult *B. chinensis* would likely also kill the majority of native aquatic snails, which could further alter native ecosystems. Adult *B. chinensis* survived 9 weeks in the laboratory without water, but in the field they may not experience such prolonged desiccation periods without receiving water from a precipitation event or condensation. Additional exposure studies could provide insight into *B. chinensis* survival in more extreme environmental conditions likely to be encountered in the field. Varying weather conditions such as low humidity, extremely high temperatures, or temperatures below freezing may increase *B. chinensis* mortality during drawdowns, although these extremes have yet to be established. Alternative methods of control should also be investigated. For instance, if a *B. chinensis* infestation in a water body is so severe that killing of native snails can be tolerated, then molluscicides may be useful. Even if a drawdown is not an effective control method by itself, our results suggest it could concentrate snails into smaller areas of water, thereby increasing the efficiency of molluscicide use.

Predation of *B. chinensis* during desiccation events should also be assessed. Many of the buried snails in our experiment were partially exposed during drawdowns, and those that were buried completely were just beneath the surface. If a large scale drawdown of a water body is found to be ineffective at killing snails directly or at concentrating them in remaining water, it may still contribute to large–scale mortality by exposing *B. chinensis* to raccoons, opossums, coyotes, and a host of other mesopredators that would otherwise not have access to them. A southeast Nebraska water body observed to contain high concentrations of *B. chinensis* in 2011 (Chaine et al. 2012) experienced a decrease in water level due to an extreme drought during the summer of 2012 (Haak et al. 2013). In August of 2012, the exposed area of the lake bottom was estimated to contain over 42,000 dead mystery snails (Haak et al. 2013), many of which were in shallow depressions that likely contained water before drying out completely (personal observation). Although the principal cause of this large snail mortality is unknown (i.e. desiccation, water temperature changes, extreme air temperatures), many of the shells were broken, supporting the idea that predation occurs when snails are exposed by drawdowns.

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