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Research Article

Short-term survival and potential grazing effects of the New Zealand mudsnail in an uninvaded Western Great Basin watershed

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Abstract

We offer a case study showing: a) the susceptibility of the Truckee River and Lake Tahoe to an invasion by the New Zealand mudsnail (*Potamopyrgus antipodarum*) and b) the short-term impacts on periphyton standing crop in the Truckee River and Lake Tahoe as a result of grazing by New Zealand mudsnails. Snail survivorship in the Truckee River experiment ranged from 50–85 percent across treatments and snail survivorship ranged from 5–40 percent in the Lake Tahoe experiment. Periphyton standing crop was negatively affected in both snail density treatments of the Truckee River experiment but the results were mixed in the Lake Tahoe experiment. Our results suggest that the Truckee River is more vulnerable to establishment by New Zealand mudsnails than Lake Tahoe.

Key words: Lake Tahoe, Truckee River, New Zealand mudsnail, *Potamopyrgus antipodarum*, periphyton

Introduction

In the Western United States ecosystem managers have turned their attention to a relatively new invader, the New Zealand mudsnail, *Potamopyrgus antipodarum* (Gray, 1843). Once established, *P. antipodarum* can rapidly spread through aquatic ecosystems. High growth rates and the ability of individuals to survive for up to three weeks out of water contribute to the species' ability to expand its range (Winterbourn 1970). *P. antipodarum* is a small snail (5 mm or less) that can establish in high densities of up to 800,000/m^2, causing a number of deleterious impacts (Kerans et al. 2005). The snails can compete with native invertebrates for algae, thus decreasing native macroinvertebrate biodiversity and biomass (Zaranko et al. 1997; Kerans et al. 2005). *P. antipodarum* do not represent a profitable food source for fish because their shells can resist digestion (Bowler 1991). The poor food quality of *P. antipodarum* and decrease in native invertebrate populations can negatively impact fish growth rates (Vinson and Baker 2008).

Lake Tahoe and the Truckee River are two interconnected aquatic ecosystems located in the western United States on the border of California and Nevada. Lake Tahoe is an oligotrophic, subalpine lake in the Sierra Nevada Mountains; it is the second deepest lake in the United States (USGS Lake Tahoe Data Clearinghouse 2008). The Truckee River is Lake Tahoe's only surface outflow, flowing northeast through Reno, Nevada and into the terminal Pyramid Lake.

Potamopyrgus antipodarum have not invaded Lake Tahoe or the Truckee River, but populations have become established in other proximate locations such as the Owens River, American River, Calaveras River, Mokelumne River, Colorado River, Putah Creek, Lake Mead, and Lake Shasta (Montana State University 2011). Given the potential for boats bringing *P. antipodarum* from infested waters to either Lake Tahoe or the Truckee River, our study had two objectives: 1) to assess the likelihood of short-

term survival and changes in snail biomass, and 2) to quantify the potential impacts of an invasion by *P. antipodarum* on periphyton standing crop and community composition. Regional land managers were interested in a fast assessment of invasion potential to assist with prioritizing management of potential aquatic invaders, so it was determined that a short term, low resolution, predictive experiment would be of management value.

Materials and methods

We conducted semi-natural laboratory experiments to determine the survivability of *Potamopyrgus antipodarum*, and its potential impacts on periphyton in the Truckee River and Lake Tahoe. Rocks with naturally occurring periphyton were placed into 75 L aquaria filled with approximately 60 L of water from each ecosystem. Each aquarium had a bottom surface measuring 30 × 60 cm. Twenty L of fresh water was brought in from the respective system every three days to diminish container and nutrient depletion effects. Two 1000 W Eye Hortilux Metal Halide grow lamps were placed above the aquaria and set to 12 h cycles to mimic natural light regimes. Environmental conditions (e.g. water temperature, dissolved oxygen, conductivity) in each aquarium were monitored every 12 hours for the 14 d duration of the experiments.

Rock substrate with periphyton was collected from the Truckee River at Idlewild Park, in Reno, Nevada and from Carnelian Bay on the North Shore of Lake Tahoe, California in spring 2006. These locations were chosen due to their accessibility and their popularity with the public for recreational fishing, swimming, and boating. The size of the individual rocks varied from 8 to 60 cm^3 and all of the aquaria were filled with a single layer of periphyton-covered rocks; the tops of the all the rocks were at least 10 cm below the surface of the water.

Snails used in the experiments were collected in Putah Creek, California. This creek forms the outflow of Lake Berryessa and is located in the Coastal Range between Sacramento and the San Francisco Bay Area. Over six percent of the boats that come to Lake Tahoe have been in Lake Berryessa in the previous seven days (Wittman 2008). Therefore, it is plausible that this particular population of snails could be transported and introduced to either Lake Tahoe or the Truckee River. After the snails were collected they were placed into an aquarium with water from Putah Creek. To insure that all snails were alive initially, only snails that were moving up the sides of the aquarium were placed in petri dishes for sub-sampling and use in the experiments.

The Truckee River experiment had a low-density treatment (LD; 2 replicates, 140 snails/m^2), a high-density treatment (HD; 2 replicates, 7400 snails/m^2), and a control (C; 4 replicates, no snails). The control allowed us to test whether the snails had a quantifiable effect on periphyton growth. Density measurements refer to the number of snails divided by the area of the aquaria bottom (1800 cm^2), not the area of rock substrate. The Lake Tahoe experiment had C, LD and HD treatments of similar densities to the Truckee River experiment, but each treatment (including C) had 2 replicates. We used relatively low snail densities to avoid the negative effects that competition for food resources would have on survival rates.

Samples of periphyton were collected from rocks before and after the experiment (n = 6 for each replicate, so n = 36 for Tahoe, and n = 48 for Truckee) by scraping a specified area (Truckee = 3 cm^2, Tahoe = 5 cm^2). The area scraped for the Tahoe experiment was larger because of lower periphyton standing crop. Samples prepared for chlorophyll-*a* analysis were frozen at -20 °C. Chlorophyll-*a* extraction was performed using a hot methanol procedure and analyzed with a spectrophotometer to determine periphyton standing crop (Eloranta 1983, Iwamura et al. 1970). Enumeration and identification of algae (genus level) was accomplished using differential interference contrast microscopy on an Olympus BX-60 (Olympus America Inc.) that was outfitted with epifluorescence capabilities. A minimum of 400 natural unit counts (cells, colonies, or filaments) were identified. The minimum count was accomplished from random fields along transects on three slides. Medium size taxa (50 µm to 200 µm) were counted at 200× (10 fields) and large taxa (> 200 µm) were enumerated at 100× (whole slide). All counts were standardized to the cobble area (cm^2). One milliliter of sub-sample was acid washed (nitric acid 50% v/v) and fixed in a diatom mounting media for viewing at 1000× to confirm the identity of diatom genera. Algal growth forms were identified using Kutka and Richards (1996) metrics that were modified from Molloy (1992).

Sub-samples of the water used in the experiments were obtained for nutrient analysis every time fresh water was collected (n = 5 for the Truckee River experiment, n = 6 for Lake Tahoe). Nitrate, ammonium, soluble reactive phosphorus, dissolved phosphorus, and total phosphorus were analyzed using standard methods (Clesceri et al. 2005; Solórzano 1969). Calcium levels were measured by mixing 20 ml of water from each of the sub-samples into two samples (one for the Truckee River and one for Lake Tahoe). These two samples were analyzed in accordance with EPA procedures (United States Environmental Protection Agency 1993).

The snails used to determine pre-treatment mean snail weight were collected from the populations used in the experiments by randomly selecting snails from petri dishes full of live snails. Snails removed from the petri dish were dried and weighed. Snails that remained in the petri dish were used in the experiments. These sub-samples, collected before and after termination of the experiment, were dried at 90ºC for 24 hours and individually weighed to determine mean snail weight using n = 150 snails for all pre-treatment (PT) weights, n = 200 for Truckee River HD post-treatment weights, and all surviving snails for the remaining treatment weights. To determine survivorship at the end of the experiment all snails in the aquaria were counted and placed into a smaller aquarium with fresh water from the respective system. A square was drawn on the bottom of the aquarium and the snails were given 48 h to move out of that square. Snails that showed no signs of movement after 48 hours were considered dead. Survivorship was determined by dividing the number of snails alive at the end of the experiment by the number of snails alive at the beginning. Growth rates are presented as percent of initial mean snail weight per day, calculated by dividing milligrams of growth per day in each treatment by the initial mean snail weight.

Statistical tests were performed on mean snail weight and chlorophyll-*a* data that had been tested for equal variances by performing a One-way ANOVA on the squared residuals and for normality using the Ryan-Joiner test (similar to Shapiro-Wilk). Multiple comparison tests (Tukey's Honestly Significant Differences) were used in conjunction with One-way ANOVAs to determine which data sets were significantly different from each other. Where data were normal but variances were found to be unequal a weighted ANOVA was used (Ott and Longnecker 2010). Mean snail weight data were normalized with a square root transformation. Pre-treatment mean snail weights were compared between the two experiments using an ANOVA. Chi-squared tests were used to assess the significance of differences in survivorship between treatments. All statistical analyses were performed using Minitab 16 (Minitab Inc., State College, PA). Graphs were created using GraphPad Prism version 4.03 (GraphPad Software, La Jolla, CA).

Results

Environmental conditions in the aquaria stayed moderately constant throughout the 14 days in both experiments (Table 1). Temperature, dissolved oxygen, and conductivity in the aquaria were similar to conditions in the field (USGS 2011a, Kolosovich personal observation). Water collected from the Truckee River (February, 2006) had higher nutrient levels than the water collected from Lake Tahoe (May, 2006). Ammonium, total phosphorus, and soluble reactive phosphorus concentrations in the waters of the two systems were all relatively similar (Table 1). Dissolved calcium (approximately 9–10 mg/L) did not seem to impact survival in the short-term. Water from the Truckee River did have slightly higher calcium concentrations (Table 1), but *P. antipodarum* are often found in waters with both high and low calcium content (Winterbourn 1970). Furthermore, Lodge et al. (1987) stated that when calcium concentrations are above 5 mg/L the success of snail establishment was governed by other factors, including food selectivity.

In both experiments snail survival rates were higher in LD than HD treatments and survivorship was significantly different between the HD treatments in the two locations (Chi square $p<0.001$) and between the LD treatments ($p<0.001$). The difference in snail survival rates between LD and HD treatments were significant in both the Truckee River (Chi square $p=0.016$) and the Lake Tahoe experiments ($p<0.001$, Table 2). Mean snail weights were not compared among locations because the snails used in the two experiments were collected from the same population but at different times and because the pre-treatment mean snail weights were different for the two experiments (ANOVA $p<0.001$, Figure 1). In the Truckee River experiment the PT, LD, and HD mean snail weights were found to be significantly different (ANOVA $p<0.001$)

Table 1. Mean chemical and physical data (± SE) for water taken from the Truckee River and Lake Tahoe. Calcium concentrations do not have ± SE because only one sample was analyzed for each experiment.

Constituent	Truckee River	Lake Tahoe
Nitrate (µg / L)	31.7 ± 6.2	4.6 ± 1.1
Ammonium (µg / L)	14.4 ± 3.2	8.6 ± 1.5
Total Phosphorus (µg / L)	36.3 ± 1.2	24.2 ± 3.8
Dissolved Phosphorus (µg / L)	22.2 ± 4.8	5.4 ± 0.5
Soluble Reactive Phosphorus (µg / L)	7.8 ± 0.8	6.2 ± 0.4
Dissolved Calcium (mg / L)	10.3	8.8
Temperature (C)	7.6 ± 0.16	9.1 ± 0.07
Dissolved Oxygen (mg / L)	11.2 ± 0.20	9.9 ± 0.06
Conductivity (µS)	74.8 ± 0.41	71.5 ± 0.30

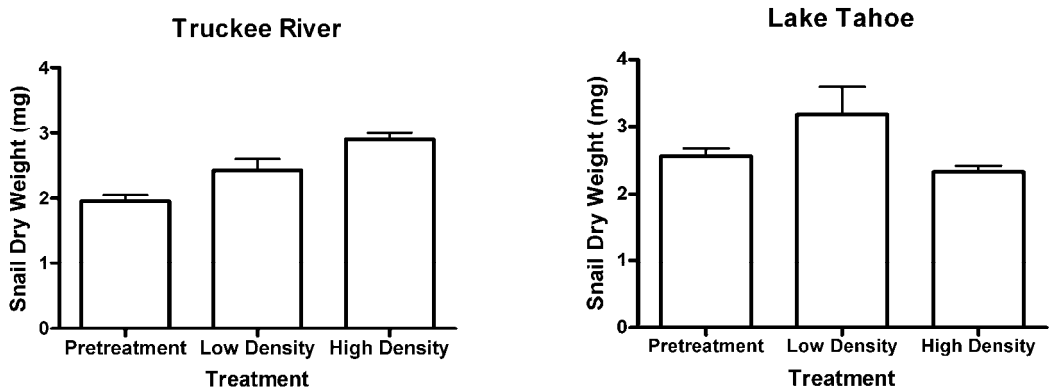

Figure 1. Mean snail weight pre-treatment, and after 14 days in Truckee River and Lake Tahoe water. Low-density treatments began with 140 snails/m^2, high-density treatments began with 7400 snails/m^2.

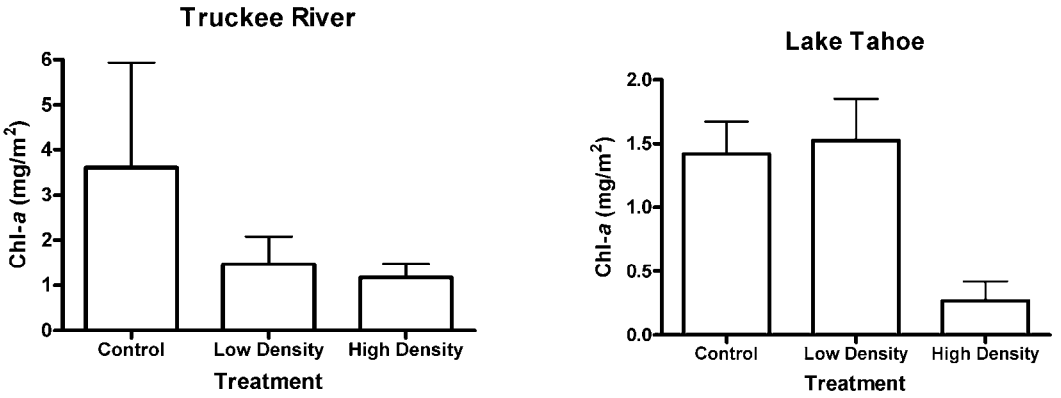

Figure 2. Chlorophyll-a after 14 days in Truckee River and Lake Tahoe water. Controls had no snails, low-density treatments began with 140 snails/m^2, high-density treatments began with 7400 snails/m^2. Chlorophyll-a was collected from periphyton, not phytoplankton. Note that the vertical axes of each graph have different scales.

Table 2. Snail survival rates and snail growth rates (± SE) after 14 days in Truckee River and Lake Tahoe water; low-density (LD) treatments began with 140 snails/m^2, high-density (HD) treatments began with 7400 snails/m^2. Growth rates are reported as percent of initial mean weight per day.

Experiment	Survival Rate (%)	Growth Rate (% / day)
Truckee LD	70 ± 14	1.746 ± 0.47
Truckee HD	55 ± 4.0	3.468 ± 0.044
Tahoe LD	32 ± 8.0	1.741 ± 0.53
Tahoe HD	6 ± 0.47	-0.641 ± 0.039

and the Tukey's Honestly Significant Difference test showed that the PT mean snail weight differed from the LD and HD mean snail weights, but the LD and HD mean snail weights were not significantly different from each other (Figure 1). The mean snail weights in the Lake Tahoe experiment were found to be normally distributed but had unequal variances so a weighted ANOVA was used to determine significance and none of the differences were found to be statistically significant (p=0.098). When snail weights are converted to growth rates (as percent of initial biomass per day) then the LD treatments in both the Truckee River and the Lake Tahoe experiments behaved very similarly (1.746 and 1.741 respectively). In the Truckee River HD treatment the snails grew by 3.468 percent of initial biomass per day and the snails in the Lake Tahoe HD treatment exhibited negative growth, losing 0.641 percent of their initial biomass per day (Table 2).

A One-way ANOVA shows that the concentrations of chlorophyll-*a* in both LD and HD treatments and the control of the Lake Tahoe experiment were significantly different (ANOVA p=0.001). The Tukey's Honestly Significant Difference test showed that the HD treatment differed significantly from the LD and the C, but the LD and the C were not significantly different. In the Truckee River experiment chlorophyll-*a* concentrations were found to be normally distributed, but the variances were not equal so a weighted ANOVA was used. The results indicate that none of the differences were statistically significant (ANOVA p=0.836, Figure 2).

In the Truckee River experiment a total of 18 diatom genera and one chlorophyte (*Stigeoclonium*) were identified. The assemblages were consistently similar (>70 %) among PT, C, LD, and HD treatments. The highly motile diatom, *Nitzschia*, was particularly abundant as well as the erect diatom *Diatoma*. In the Lake Tahoe experiment, 24 diatom genera, one cyanophyte (*Oscillatoria*), and two chlorophytes (*Stigeoclonium* and *Cosmarium*) were identified. These diatom-dominated assemblages were also consistently similar (>80% similarity) among PT, C, LD, and HD treatments. The araphid diatoms, *Synedra* and *Fragilaria*, dominated the Tahoe assemblages, thus inflating the relative abundance of erect growth forms. The primary substrate for these abundant erect taxa appeared to be excessive stalks (extracellular polymeric substances) produced by the diatoms, *Gomphonema* and *Gomphoneis*. These stalks did appear to decrease in the HD treatments. Stalks were also present in the Truckee biofilms, though not as excessive as in the Lake Tahoe experiment.

Discussion

Our results suggest that the Truckee River may be more susceptible than Lake Tahoe to an invasion by *Potamopyrgus antipodarum*. In the Truckee River experiment, snails had higher growth rates in the HD treatment than the LD treatment; however, survival rates were higher in the LD treatment (Table 2, Figure 1). The results of the ANOVA showed that mean snail weights in both LD and HD treatments were significantly different from the PT weight. This indicates that the snails did grow in both Truckee River treatments but the higher post-treatment mean snail weight in the HD treatment was not significantly different from the LD treatment. Generally >50 % of snails survived and grew at both densities in Truckee River water, suggesting the potential to persist in this environment.

The Lake Tahoe experiment suggested low to moderate survival rates in that environment, with a decline in mean snail weight during the experiment timeframe in the HD treatment (Table 2). At the low density of 140 snails/m^2, snails survived and grew. However, at the higher density of 7400 snails/m^2, survivorship was very low (6%), and growth over 14 days was negative, suggesting difficulty in persisting in the Lake Tahoe environment at this density. In the Lake Tahoe experiment, periphyton in the HD treatment was grazed to such low levels that food availability may have been the main factor

limiting survivorship and growth (Figure 2). Lake Tahoe is an oligotrophic ecosystem and periphyton productivity may not sustain high densities of *P. antipodarum*. It is possible that in the Lake Tahoe HD treatment, periphyton became so sparse and resource competition so high, that grazing became an activity in which the snails exhibited a net loss of energy.

Snails tend to be effective grazers that can control algal biomass and community structure. The current work shows strong evidence of top-down effects on periphyton standing crop; however, there was no indication that the community structure was affected. Previous research suggested that physiognomy may not always be a good predictor of the susceptibility of different algae to grazing (Wellnitz and Ward 1998). Similarly, Villanueva et al. (2004) found little change in the periphyton community composition due to grazing by another snail, *Chilina dombeiana* (Bruguiere, 1789). However, the duration of the current study may not have been enough time to result in a change in community structure due to grazing. Some studies did not see a divergence in similarity between their grazing treatments until after day 16 (Lamberti et al. 1987; Steinman et al. 1992). The excessive amounts of stalk material in the Tahoe periphyton likely increased the carbon content of the biofilm grazed by snails, thereby increasing the carbon relative to nitrogen and phosphorus. Thus, the potential stoichiometric imbalance of Tahoe periphyton may have impaired survivability by providing poorer food quality compared to the Truckee River periphyton (Sterner and Elser 2002).

After 14 days the systems might not have reached equilibrium and, given more time, snails in the Truckee River HD treatment could have experienced a population crash as well. Ideally, the experiment would have occurred over more than 14 days, but the need for immediate information to assist with ongoing management decisions as well as funding limitations necessitated the short duration of the experiments. In fact, results from this, as well as other studies in the region, led to the establishment of new guidelines for boat permitting and inspection at Lake Tahoe to proactively reduce the likelihood of nuisance aquatic species introductions (TRPA 2010; USACE 2009). As of June 2011 *P. antipodarum* have not been found to be in Lake Tahoe nor the Truckee River (Montana State University 2011; USGS 2011b).

Potamopyrgus antipodarum has a strong ability for widespread colonization because of its environmental adaptability including tolerance of broad thermal ranges, osmotic concentrations, flow, disturbance regimes, and substrates (Winterbourn 1970; Hylleberg and Siegismund 1987; Quinn et al. 1994; Schrieber et al. 2003; New Zealand Mudsnail Management and Control Working Group 2006; Butkus et al. 2012; Moffit and James 2012). The most effective way to minimize impacts is to prevent or slow snail introductions to new ecosystems. Since invasion vectors can include boats or other personal equipment (fishing gear, boots, etc), and the success of this species is a function of the clone present and local environmental conditions, ecosystem-specific experiments are important for determining survivability and the potential of *P. antipodarum* to successfully invade specific waterways. We offer a case study showing that the short–term survival of adult snails is possible in the nutrient poor ecosystems of the Western United States. Given that over 50% of the snails survived and exhibited measurable growth in both snail density treatments of the Truckee River experiment, our results indicate that if these snails are transported to the Truckee River, they will be able to prosper in high densities. The Truckee River is a popular fishing destination for the residents of Reno, NV, especially because it flows through the center of town. It is also connected to other lakes that are popular among fishermen (e.g. Virginia Lake, Pyramid Lake, and Washoe Lake). Local, state, and Native American tribal agencies should be proactive in investigating survival and growth potentials of invasive species in western waterways. Such information would aid in predicting potential outcomes of species invasions and could be used to prioritize what species and ecosystems should be of primary concern.

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