

**Impacts of Chinese mystery snail (*Cipangopaludina chinensis*)
presence on native snail and bivalve populations**

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Abstract

The Chinese mystery snail (*Cipangopaludina chinensis*, or CMS), a species native to East Asia, has become widely established in the United States and may be negatively impacting native snail populations, while its effects on native freshwater bivalves are unknown. My study examined the influence of CMS on survivorship of native snails and bivalves with exclusion cages on two creeks in the Upper Peninsula of Michigan. There were no significant differences in native snail or bivalve populations between cages with snail populations left intact and populations with CMS removed, indicating either a flaw in experimental design or that CMS have no effect on these animals. In addition, there was no significant difference in native snail and CMS populations between different mesh sizes used to attempt to exclusively restrict movement of CMS. However, bivalve populations were found to be significantly higher in Tenderfoot Creek than in Brown Creek, perhaps due to the open vegetation and substrate composition in the part of Tenderfoot Creek tested. Native snail and bivalve populations were found to be higher in exclusion cages than in similar unfenced areas, possibly due to lower water flow rate in the cages. As the effect of CMS on native snails and bivalves could not be determined, conservation efforts should not be altered from current practices for now. Further studies could focus on mesocosm experiments involving CMS impact on native snail and bivalve communities and examine bivalve populations across habitat types.

Introduction

Our environment is an intricate balance. Every species in an ecosystem is connected to each other, either directly or indirectly, and a change to even a single species can cause a cascade that significantly alters the ecosystem. Such a change can occur when a new species is introduced to an already-established ecosystem. Each species in a local ecosystem is finely tuned to the conditions and other species in its habitat. However, when a more competitive foreign species enters the habitat, it can outcompete populations of similar native species, as it lacks the restraints of its old ecosystem (Mooney and Cleland 2001).

The Chinese mystery snail (*Cipangopaludina chinensis*, or CMS), a species of invasive freshwater snail, are becoming an issue worldwide. Native to East Asia (Chiu et al. 2002), they have now become established in many parts of North America and Europe. CMS first appeared in San Francisco at Asian food markets in the 1980s (Jokinen 1982). They are large snails, generally 2-3 cm in width (Chiu et al. 2002). CMS live in stagnant or slow moving water with a

muddy or silty bottom (Distler et al. 2003) at a maximum depth of 3 meters (Jokinen 1982; Jokinen 1992).

CMS invasion poses a major problem for conservation of natural aquatic habitats in North America. They can potentially outcompete native snails due to several factors. First, they need to eat more than native snails, reducing food available to native snails (Sura 2009). CMS have thicker shells than native snails, allowing them to better survive rusty crayfish (*Orconectes rusticus*) predation (Johnson et al. 2009). CMS could also have higher fecundity: they live for 4-5 years, increasing the total offspring they can produce, bear live young, removing the potential for eggs to be preyed upon (Distler et al. 2003), and reproduce very fast, birthing an average of 30 individuals per year (Stephen et al 2013). All of these elements contribute to an invasive snail that could outbreed, out-eat, and out-survive native snails.

Studies have shown mixed results of CMS on local ecology. One experiment found that the presence of CMS decreased native snail populations (Johnson et al. 2009). Another study found that CMS affect the composition of native algae and bacterial communities, possibly causing unexpected changes to the ecosystem (Olden et al. 2013). However, a third study found that CMS had little effect on native snail populations (Solomon et al. 2009).

Chinese mystery snails are difficult to contain and control methods are limited. CMS can easily be transported by boat to new lakes, as their operculum prevents desiccation and allows them to survive outside of water for months (Havel 2011; Havel et al. 2014; Unstad et al. 2013). Suitable methods for control, such as checking boats before transportation to a different lake, only prevent the spread of CMS (Indiana DNR 2005). CMS cannot travel against a strong current, but again, this only prevents CMS from entering new territory (Rivera 2008). Existing

extermination methods like copper compounds or introduction of non-native CMS predators can harm native snail species (Indiana DNR 2005).

One little-examined impact of CMS infestation is their impact on freshwater bivalve communities. Historically, bivalves were widespread in North America's Midwest, but now more than half of these species are endangered. Since bivalves filter feed (U.S. Fish and Wildlife Service 2019), and CMS both filter feed and scrape surfaces using their radula (Olden et al. 2013), bivalves and CMS could potentially compete for resources in the same way that CMS compete with native snails.

My research had two objectives. First, I conducted an exclusion experiment to determine if Chinese mystery snails decrease survivorship in native snail and bivalve populations. I used control and experimental mesh fence enclosures, removing CMS from the experimental cages and allowing only native snails and bivalves to remain; I left CMS, native snails, and bivalves in the control cages. Comparing the experimental and control cages allowed me to determine if CMS had a negative effect on native snail and bivalve populations and whether removing CMS from CMS-infested waters could allow native snail and bivalve populations to recover. Second, I tested varying mesh hole sizes to determine the optimal mesh size that allowed the smaller native snails to freely pass through while blocking the larger CMS. The optimal mesh size could be used to develop traps for CMS as a safer alternative to chemical measures, as trapping could be a useful management option if CMS do indeed negatively affect native snail populations.

My hypothesis was that removal of CMS from experimental exclusion cages would affect native snail and bivalve survivorship and that mesh size would impact permeability of both CMS and native snails. Specifically, I predicted that native snails and bivalves in the control exclusion cages would have a significantly greater percent decrease in population than the experimental

exclusion cages, and a mesh hole size of 1 inch (2.54 cm) would be optimal to allow native snails to pass through the mesh and prevent CMS from passing through the mesh.

Methods

Location

All experiments were conducted on Tenderfoot Creek and Brown Creek (Figure 7) on property at the University of Notre Dame Environmental Research Center. The property is located in a mixed forest with plentiful wetlands on the border between the Upper Peninsula of Michigan and Wisconsin.

Exclusion cages

I tested the effects removing CMS from bodies of water had native snail and bivalve populations for approximately a month in June and July 2019. On Week 0, I set up exclusion cages at Tenderfoot Creek and Brown Creek. On each creek, 8 exclusion cages were erected, 4 of which were controls and 4 of which were experimentals. This resulted in 8 controls and 8 experimentals across both creeks. Each exclusion cage consisted of a 1x1 m² fence composed of window screen to prevent any snails from entering or exiting the enclosures. The resulting square fences were taller than the creeks' water levels to account for variations in water level. Any fish or tadpoles were removed from the enclosures. Each control was paired with an experimental in similar conditions. The 8 pairs of controls and experimentals initially contained native snails, bivalves, and CMS.

After the cages were set up, sediment at the bottom of each cage was swept through with fine-mesh nets for 12 person-minutes to collect native snails, bivalves, and CMS. Vegetation was also checked for these animals. The native snails, bivalves, and CMS were identified, separated,

and counted. The population counts (total native snail frequency, total bivalve frequency, and total CMS frequency) from each cage were recorded. For the control exclusion cages, native snails, bivalves, and CMS were returned back to the cages. For the experimental exclusion cages, native snails and bivalves were returned to the cages and CMS were placed outside the cages. Thus, the controls contained native snails, bivalves, and CMS while the experimentals had CMS removed. Population measurements were repeated two more times at both Tenderfoot Creek and Brown Creek, each measurement occurring approximately two weeks after the last measurement. In total, populations were measured on Week 0, Week 2, and Week 4. After the final population measurement on each creek, the cages were removed and disassembled.

During Week 4, population counts were taken at unfenced areas on both Tenderfoot Creek and Brown Creek. Four 1x1 m² areas, each located in similar conditions to a control and experimental cage pair, were sampled using the population count procedures described above. This allowed for a comparison of Week 4 populations of native snails, CMS, and bivalves between relatively undisturbed parts of the streams and the enclosed control cages. In addition, native snail and CMS aperture width (mm) perpendicular to the shell apex and bivalve shell width (mm) were measured for each specimen collected to compare sizes of animals between the two creeks.

Immediately before population counting was conducted on a particular cage or unfenced area, chlorophyll A ($\mu\text{g/L}$) and pH were measured in the cage. These readings were taken to confirm that conditions were similar between cages.

Selectively trapping Chinese mystery snails

I tested different mesh sizes to determine if there was a mesh size that allowed native snails to move freely through while preventing adult CMS from crossing. Mesh size of 0.25, 0.5,

1.0, 1.5, and 2.0 inches (0.64, 1.27, 2.54, 3.81, and 5.08 cm) was examined. Three one-meter circumference fences of each mesh size were set up in Tenderfoot Creek on Week 0. 15 fences were erected in all, with each mesh size having 3 replicates. All fences were put in similar conditions near the bank in shallow water to control for other variables. Each enclosure was then swept with a fine-mesh net for three minutes to collect native snails and CMS. Vegetation was also checked for snails. Native snails and CMS were identified, separated, counted, and then deposited outside the fences. All 15 enclosures were checked at Week 2 and Week 4 using the same procedures. The cages were then removed and disassembled.

Statistical tests

All statistics were calculated in R using the R Commander interface, except for chi squared tests, which were calculated by hand in Excel. A chi squared chart was used to determine significance of chi squared values (The University of Queensland, Australia School of Mathematics and Physics n.d.). All graphs were designed in Microsoft Excel. Square root transformations were conducted on all control and experimental exclusion cages and unfenced zones to make the data as normal as possible. A significance level of 0.05 was used.

Square root transformations of native snail, CMS, and bivalve populations for control and experimental cages and unfenced zones were checked for normality using Shapiro-Wilk tests. Native snail and CMS aperture width perpendicular to the apex of the shell and bivalve shell width were also checked for normality using Shapiro-Wilk tests. A chi squared test was used to determine if pH and chlorophyll A measurements for control and experimental cages differed significantly from their average values. The four replicates for each creek and day were averaged, but otherwise all data was factored in. Box plots created in R were also used to look for outliers and changes in pH and chlorophyll A.

After square root transformations, if data was found to be normal in exclusion cages, the following ANOVA tests were used. If data was found to be not normal for exclusion cages, the data was tested using paired-sample Wilcoxon tests.

Two-way ANOVA tests were used to determine the difference in square root transformations of native snail, CMS, and bivalve populations between the 8 control and 8 experimental exclusion cages at Week 0, Week 2, and Week 4. This could indicate if there was a significant difference between the control and experimental cages or a significant difference between creeks sampled.

Two-way ANOVA tests were used to determine the difference in square root transformations of native snail, CMS, and bivalve populations sampled during Week 4 between the 8 unfenced zones and 8 control cages, as well as the 8 unfenced zones and 8 experimental cages. This could indicate if there was a significant difference between the unfenced zones and control and experimental cages or a significant difference between creeks sampled.

Unpaired t-tests were used to determine if there was a significant difference in native snail shell aperture width, CMS shell aperture width, and bivalve shell width between Tenderfoot Creek and Brown Creek.

A chi squared test was used to determine if the averages of the replicates collected Week 2 and Week 4 of each mesh size (0.25, 0.5, 1.0, 1.5, and 2.0 in) varied significantly in native snails or CMS entering the cages after having been removed during the previous collecting period.

Results

After square root transformation, the total populations of native snails ($W=0.95975$, $p\text{-value}=0.09868$) and bivalves ($W=0.96325$, $p\text{-value}=0.1365$) collected in the control and experimental cages across all weeks of testing were found to have normal distribution, allowing for parametric testing to be conducted on them. Native snail ($W=0.95376$, $p\text{-value}=0.749$), CMS ($W=0.96867$, $p\text{-value}=0.8874$), and bivalve ($W=0.82239$, $p\text{-value}=0.04944$) populations from unfenced collecting during Week 4 were normally distributed. All native snail and CMS aperture width and bivalve shell width data was found to be normally distributed (Table 1). Neither average chlorophyll A ($df=11$, Chi^2 value= 7.503424658, $p\text{-value}$ between 0.10 and 0.90) or pH ($df=11$, Chi^2 value= 0.1398527, $p\text{-value}$ greater than 0.995) were found to deviate significantly from their average values, indicating that these two measurements did not change significantly over the course of the measuring period or between creeks or treatments.

Out of all two-way ANOVA tests comparing treatments and creeks within each week, only three were significant. Week 0 ($df=1$, creek $F=25.4314$ creek $p\text{-value}=0.0002879$), Week 2 ($df=1$, creek $F=29.4306$, creek $p\text{-value}=0.0001537$), and Week 4 ($df=1$, creek $F=12.2258$, creek $p\text{-value}=0.00441$) bivalves had significantly greater populations in Tenderfoot Creek than in Brown Creek (Figure 4; Table 2).

Other two-way ANOVA tests, exploring the relationship between unfenced zones, control cages, and experimental cages collected during Week 4, showed more relationships. The native snail populations ($df=1$, treatment $F=18.3690$, treatment $p\text{-value}=0.001058$) and bivalve populations ($df=1$, creek $F=9.3690$, creek $p\text{-value}=0.009883$) were lower in unfenced zones than in control cages (Figure 5; Table 3). Native snail and bivalve populations between unfenced zones and experimental cages were not significant. Bivalve populations within both unfenced-

control tests ($df=1$, creek $F=9.3690$, creek $p\text{-value}=0.009883$; Table 3) and unfenced-experimental tests ($df=1$, creek $F=12.3668$, creek $p\text{-value}=0.00425$; Table 4) were greater in Tenderfoot Creek than in Brown Creek.

There was no significant difference in native snail aperture width ($df=5.119$, $t=1.5231$, $p\text{-value}=0.1869$), CMS aperture width ($df=5.8331$, $t=-0.93217$, $p\text{-value}=0.3882$), or bivalve shell width ($df=4.145$, $t=-1.6296$, $p\text{-value}=0.176$) between Tenderfoot Creek on Brown Creek on Week 4 (Figure 6). Additionally, populations of native snails ($df=4$, Chi^2 value=7.84741784, $p\text{-value}$ between 0.05 and 0.10) and CMS ($df=4$, Chi^2 value=6.581267218, $p\text{-value}$ between 0.10 and 0.90) found in the different mesh size cages (0.25, 0.5, 1.0, 1.5, and 2.0 in) were not found to deviate significantly from the average populations.

Even after square root transformation, the total population of CMS in the control and experimental cages across all weeks of testing ($W=0.94137$, $p\text{-value}=0.01832$) was found to not have normal distribution, as a standard Shapiro-Wilk test requires a $p\text{-value}$ of 0.05 or higher to indicate normality. Thus, CMS data was tested using a paired-sample Wilcoxon test. Populations of CMS ($V=144.5$, $p\text{-value}=0.8551$) were found to be not significantly different between control and experimental exclusion cages across all weeks and creeks.

The three main native snail species caught were *Lymnaea stagnalis*, *Helisoma trivolvis*, and *Physa acuta*. Bivalves that were caught were from the *Sphaerium* genus.

Discussion

I hypothesized that there would be more native snails and bivalves in experimental cages than in control cages, since both native snails and bivalves were expected to have higher survivorship and reproduction in the absence of CMS competitors. I had predicted that, since CMS have harder shells, high reproduction rates, and high nutritional intake, they would survive

predators better than native species and outbred and out-eat the native snails and bivalves. However, there were no cases in which native snails or bivalves had significantly higher populations in experimental cages than in control cages (Figures 1, 2, and 3; Table 2). This suggests that CMS presence had neither a positive or negative effect on native snail and bivalve populations, contrary to what I had expected.

Two possibilities must be considered here. First, the absence of a significantly greater population of native snails and bivalves in experimental cages could be due to experimental error. The time period over which exclusion cages were out in the water could simply have not been long enough for changes in food availability or reproduction to occur. Second, collection methods may also have been less than optimal. Minuscule snails, both native and CMS, and bivalves could have been missed while collecting, altering the populations measured. Collecting was conducted via fine-mesh nets for 12 person minutes per cage, perhaps too short a time to search through all the sediment and locate a substantial fraction of snails in the cage. In particular, failure to remove enough CMS from experimental cages would result in limited reduction of CMS populations in experimental cages. This in turn would result in limited impact on native snail and bivalve communities in experimental cages, bringing their populations more in line with control cages. This indeed is most likely the case, since no significant difference in CMS populations between control and experimental cages was found. This indicates that not enough CMS were removed to have a noticeable difference in CMS population between treatments.

Other environmental variables could have affected results, too. First, there was no floor to the cages. Instead, the bottom of the cage walls simply stopped once the sediment was reached. This may have allowed bivalves to enter and exit the cages, since, for although they are usually

stationary, they can burrow through sediment (U.S. Fish and Wildlife Service 2019). Meanwhile, the snails could not escape the cages, since they cannot burrow through river bottoms. Also, all cages were installed out in the field, so random changes in weather and creek water level is inevitable. This unpredictability could have led to changes in populations measured.

If the experimental design did indeed work, it could be the case that CMS do not have any significant impact on native snail and bivalve populations. This supports Solomon et al.'s (2009) findings, who, in a study observing northern Wisconsin lakes, reported that CMS had no strong effect on native snail assemblages. If this is true, the regulation of CMS to benefit native snails and bivalves should not be a high priority concern. CMS, although they are invasive, should not have resources diverted from other well-studied harmful invasive species such as zebra mussels (*Dreissena polymorpha*).

Unfortunately, since native snail and bivalve populations did not differ significantly between control and experimental cages, I am unable to determine whether CMS harm the native invertebrates I studied. Thus, my conclusion on this part of my experiment is that more research is necessary to determine whether CMS do actually have an impact on native snail and bivalve populations.

Intriguingly, bivalves were found to have higher populations in Tenderfoot Creek in all weeks sampled (Figure 4, Tables 2, 3, and 4). This indicates that the particular part of Tenderfoot Creek I sampled from is a better environment for bivalves than Brown Creek. Tenderfoot Creek has a more open environment than Brown Creek. Less vegetation clogs the banks of the Tenderfoot Creek and thinner foliage populates the shoreline. This could allow for more nutrients to enter the creek, giving bivalves more options for food. In turn, more nutrition could result in higher bivalve population densities on the creek. In addition, I noticed that the substrate

of Tenderfoot Creek contained more sediment, such as silt, and less vegetation debris than Brown. The bivalve species present on these creeks may prefer sediment to secure themselves to over dead vegetation, further increasing the habitability of Tenderfoot Creek.

During Week 4, there were more native snails and bivalves in exclusion cages than in unfenced zones (Figure 5, Table 3), indicating that they preferred the cages over undisturbed creek. The slower flow rate of organic matter through the cages could be easier for the bivalves to filter. Similarly, slower water could allow more debris that snails feed on to settle, instead of carrying sediment downstream. In addition, faster water could have the potential to dislodge both snails and bivalves from their substrate more readily. Indeed, *L. stagnalis*, one of primary species collected, prefers slow-moving or stagnant water (Van Damme and Ghamizi 2010).

There was no significant difference in native snail aperture, CMS aperture, or bivalve shell width between Tenderfoot Creek and Brown Creek, although their means between each week might appear to suggest otherwise (Figure 6). This signifies that all three groups are likely able to grow to similar dimensions on both creeks.

The different sized mesh cages were intended to indicate which mesh size (0.25, 0.5, 1.0, 1.5, or 2.0 in) best allowed the smaller native snails to pass through and block the larger CMS. The enclosure with the mesh size that had the maximum average number of native snails and the minimum average number of CMS measured on Week 2 and Week 4 could potentially be the optimal mesh size to create CMS traps. A mesh size of 1 inch was predicted to be the best size, as CMS tend to be 2-3 cm (0.79-1.18 in) as adults (Chiu et al. 2002). However, there was no significant difference in either native snails or CMS, which presumably would be entering the cages after removal during the previous collection, found in the cages during Week 2 and Week 4. This could indicate one of two possibilities. It could show that different mesh sizes did not

actually have any effect, especially since most of the native snails and CMS collected were smaller than 0.25 inches and could move freely in or out of even the 0.25-inch mesh size. Otherwise, it could be due to experimental error. Since each cage was only checked for 5 person-minutes and many of the snails were very small, some of the snails could have been passed over during collection, resulting in more snails in the cages than intended. This could have overshadowed any snails that actually entered the cages.

Future studies could examine several aspects related to this study. First, cages could be checked for more person minutes with finer-mesh nets. Instead of simply collecting snails and bivalves from the cages with nets, supplemental methods could be used, like taking core samples from the sediment, to obtain a more accurate population measurement for the cage. More replicates of cages could be used to increase sample size and the power of statistical tests. Finally, cages could be put in the creeks for longer periods of time, perhaps two or three months or even multiple years, to study the longer-term impact CMS have on native snails and bivalves.

Since experiments in the field inherently have many uncontrollable variables, mesocosm experiments could be conducted to supplement experiments in actual bodies of water. Native snail species, CMS, and bivalves could be collected and deposited in chambers controlled for aspects like pH and algal concentration. Then, native snails and bivalves could be placed in some chambers, while native snails, bivalves, and CMS could be placed in others. Among other variables, snail growth, mortality, and birth events could be periodically measured. Different mesh sizes could also be tested in similar chambers. Although mesocosm experiments could not replicate all the conditions found in the field, they would allow for a more controlled environment in which to study the effects of CMS on native snails. Finally, the detection of more bivalves at one creek suggests that habitat could have a profound impact on the species and

population densities of bivalves. Perhaps an observational study could compare bivalve assemblages at different habitats in northern wetland ecosystems.

Overall, my experiment yielded inconclusive results. Native snail and bivalve populations did not vary significantly between control and experimental cages, either due to CMS having no actual impact on native snails or bivalves, or due to a flaw in experimental design. In addition, cages of varying mesh sizes had no difference in native snail or CMS populations, perhaps suggesting that mesh size had no impact on snail movement. However, both native snails and bivalves preferred exclusion cages to undistributed areas of the creeks, possibly due to lower water flow rate within the cages. Also, bivalves were found to have higher populations on Tenderfoot Creek than Brown Creek, perhaps due to the open vegetation and particular substrate composition of Tenderfoot Creek.

For now, I would recommend that management strategies should not be altered from their current state. I would urge caution, since I could not determine the effects CMS have on native snails and bivalves; I certainly encourage organizations to continue to raise awareness of CMS and ways to prevent their spread, such as the Illinois DNR's website on CMS (Indiana DNR 2005). However, at the same time, I would not advocate for further prevention actions, such as extermination methods, than already exist, since conservation efforts can only be spread so thin. Already-pervasive invasive species like zebra mussels demand more immediate attention. Thus, more research will be key to determining whether CMS indeed have an impact on native snails and bivalves. In the end, only a thorough understanding of the effects of the invasive Chinese mystery snail can help ecologists and policy makers best direct their resources employed for the conservation of freshwater environments.

Tables

Table 1. Shapiro-Wilk tests for native snail and CMS aperture width perpendicular to the apex of the shell and bivalve shell width.

Data tested	Replicate number	W statistic	P-value
Native snail Brown aperture width	n=11	W = 0.8858	p-value = 0.364
Native snail Tenderfoot aperture width	n=22	W = 0.84179	p-value = 0.2007
CMS Brown aperture width	n=23	W = 0.8256	p-value = 0.1566
CMS Tenderfoot aperture width	n=15	W = 0.98085	p-value = 0.907
Bivalve Brown aperture width	n=52	W = 0.85908	p-value = 0.2569
Bivalve Tenderfoot aperture width	n=7	W = 0.98527	p-value = 0.9322

Table 2. Two-way ANOVA tests for square root transformations of native snail and bivalve populations between control and experimental exclusion cages at Week 0, Week 2, and Week 4 across both creeks (n=4 per treatment per creek).

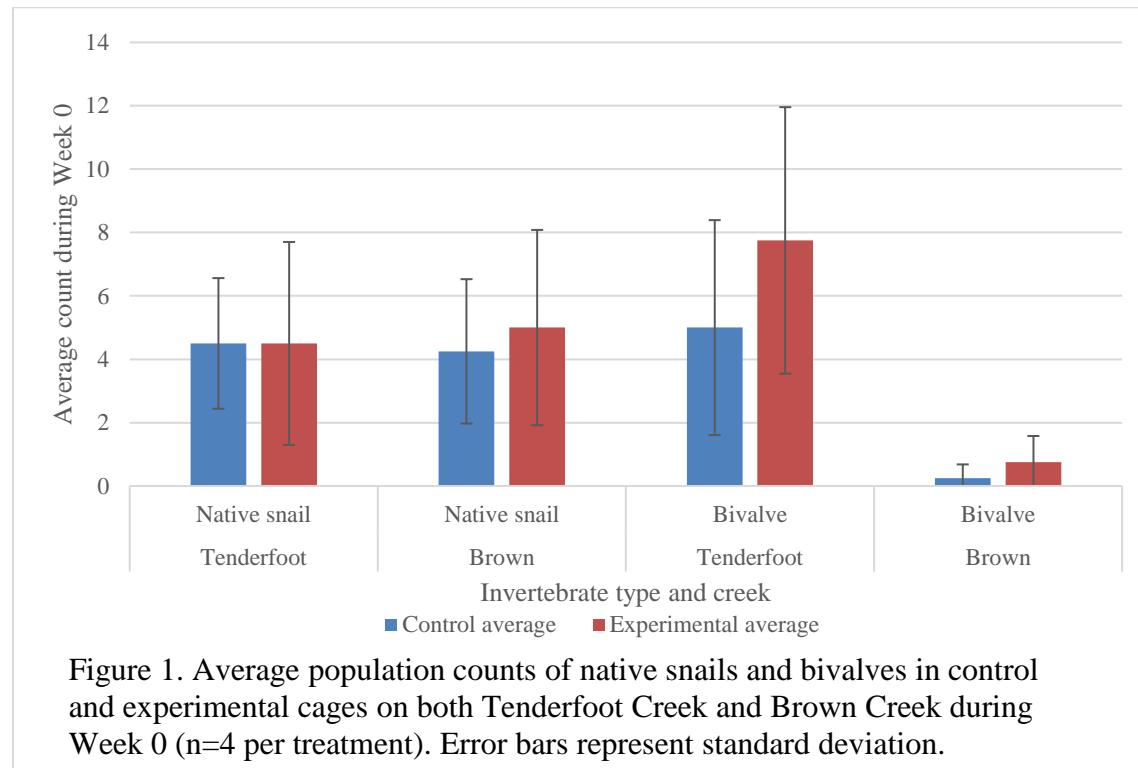
Data tested	Degree of freedom (creek)	F value (creek)	P value (creek)	Degree of freedom (treatment)	F value (treatment)	P value (treatment)	Degree of freedom (creek x treatment)	F value (creek x treatment)	P value (creek x treatment)	Brown x control mean	Brown x experimental mean	Tenderfoot x control mean	Tenderfoot x experimental mean
Native snails Week 0	1	0.0969	0.7609	1	0.0183	0.8947	1	0.2175	0.6493	1.993673	2.136153	2.060376	1.801557
Native snails Week 2	1	0.2195	0.6478	1	1.0747	0.3203	1	0.1615	0.6948	1.786566	2.351230	2.128194	2.377364
Native snails Week 4	1	4.3891	0.05806	1	0.8544	0.37352	1	0.2637	0.61692	2.540569	1.906595	3.237883	3.056735
Bivalves Week 0	1	25.4314	0.0002879	1	1.4858	0.2462925	1	0.0942	0.7641857	0.250000	0.6035534	2.085955	2.6774440
Bivalves Week 2	1	29.4306	0.00001537	1	0.0234	0.8808951	1	4.6519	0.0520049	1.465926	2.118034	3.933358	3.181627
Bivalves Week 4	1	12.2258	0.00441	1	0.3975	0.54018	1	1.1739	0.29989	2.177562	1.398939	3.273771	3.479538

Table 3. Two-way ANOVA tests for square root transformations of native snail and bivalve populations sampled during Week 4 between unfenced zones and control cages across both creeks (n=4 per treatment per creek).

Data tested	Degree of freedom (creek)	F value (creek)	P value (creek)	Degree of freedom (treatment)	F value (treatment)	P value (treatment)	Degree of freedom (creek x treatment)	F value (creek x treatment)	P value (creek x treatment)	Brown x control mean	Brown x unfenced mean	Tenderfoot x control mean	Tenderfoot x unfenced mean
Native snails	1	0.5438	.475032	1	18.3690	0.001058	1	3.6225	0.081261	2.540569	1.911411	3.237883	1.603553
Bivalves	1	9.3690	0.009883	1	7.5215	0.017847	1	0.0197	0.890608	2.177562	1.286566	3.273771	2.286566

Table 4. Two-way ANOVA tests for square root transformations of native snail and bivalve populations sampled during Week 4 between unfenced zones and experimental cages across both creeks (n=4 per treatment per creek).

Data tested	Degree of freedom (creek)	F value (creek)	P value (creek)	Degree of freedom (treatment)	F value (treatment)	P value (treatment)	Degree of freedom (creek x treatment)	F value (creek x treatment)	P value (creek x treatment)	Brown x experimental mean	Brown x unfenced mean	Tenderfoot x experimental mean	Tenderfoot x unfenced mean
Native snails	1	1.0400	0.3279	1	3.0753	0.1050	1	3.1163	0.1029	1.906595	1.911411	3.056735	1.603553
Bivalves	1	12.3668	0.00425	1	2.2204	0.16200	1	1.5217	0.24098	1.398939	1.286566	3.479538	2.286566

Figures

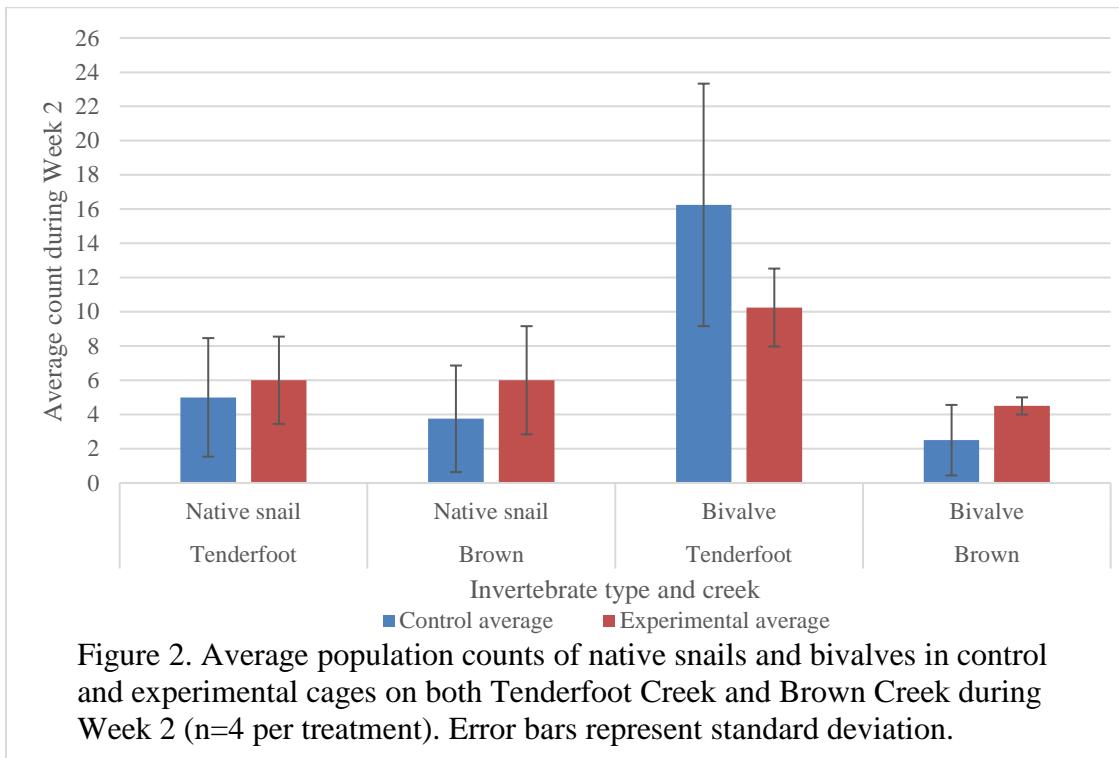


Figure 2. Average population counts of native snails and bivalves in control and experimental cages on both Tenderfoot Creek and Brown Creek during Week 2 (n=4 per treatment). Error bars represent standard deviation.

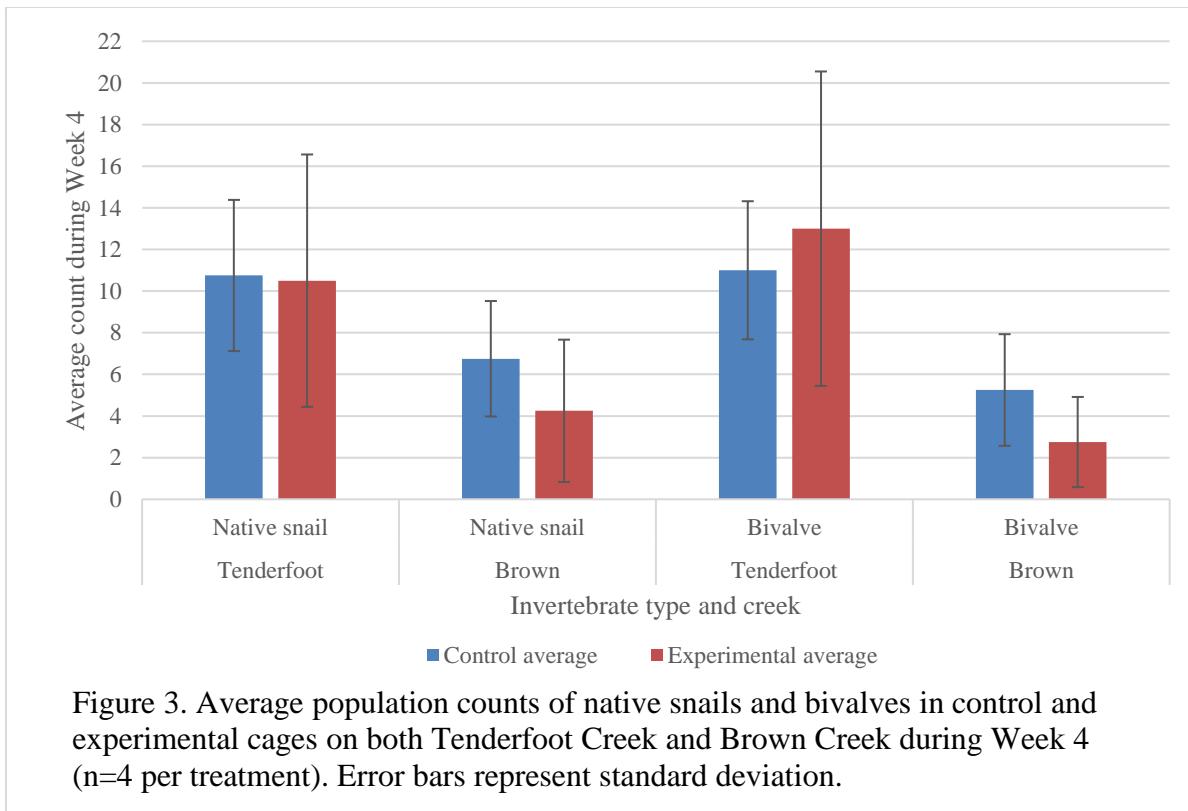


Figure 3. Average population counts of native snails and bivalves in control and experimental cages on both Tenderfoot Creek and Brown Creek during Week 4 (n=4 per treatment). Error bars represent standard deviation.

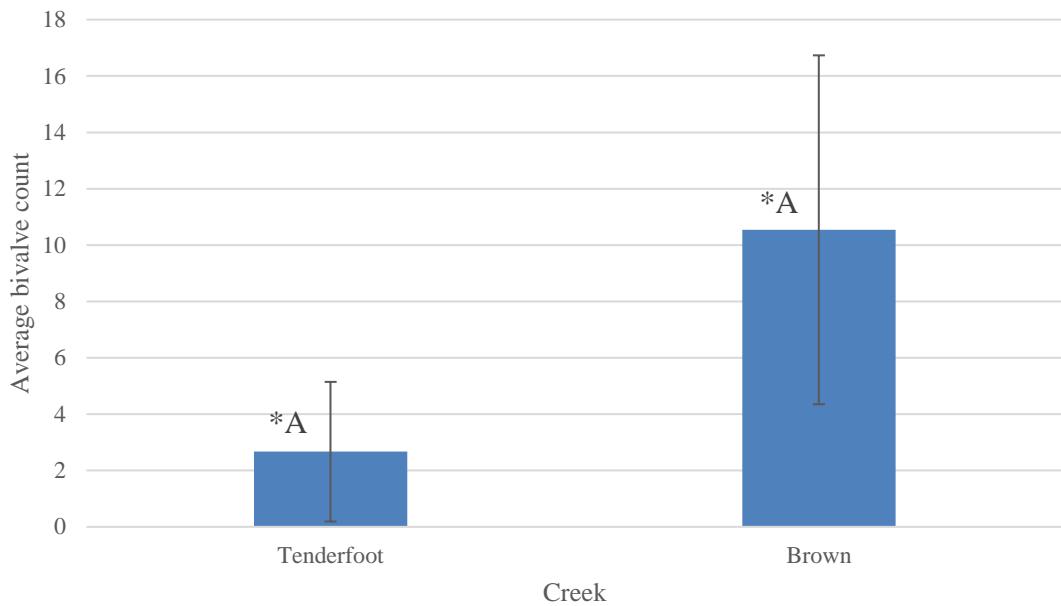


Figure 4. Average bivalve population count per lake across all cages and weeks (n=24 per creek). Error bars represent standard deviation.

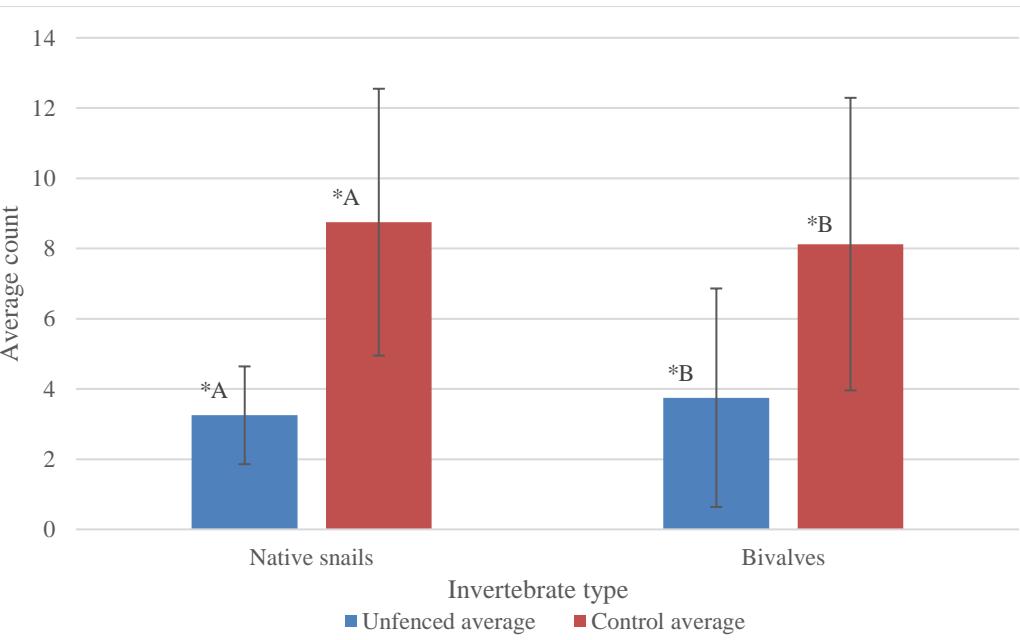
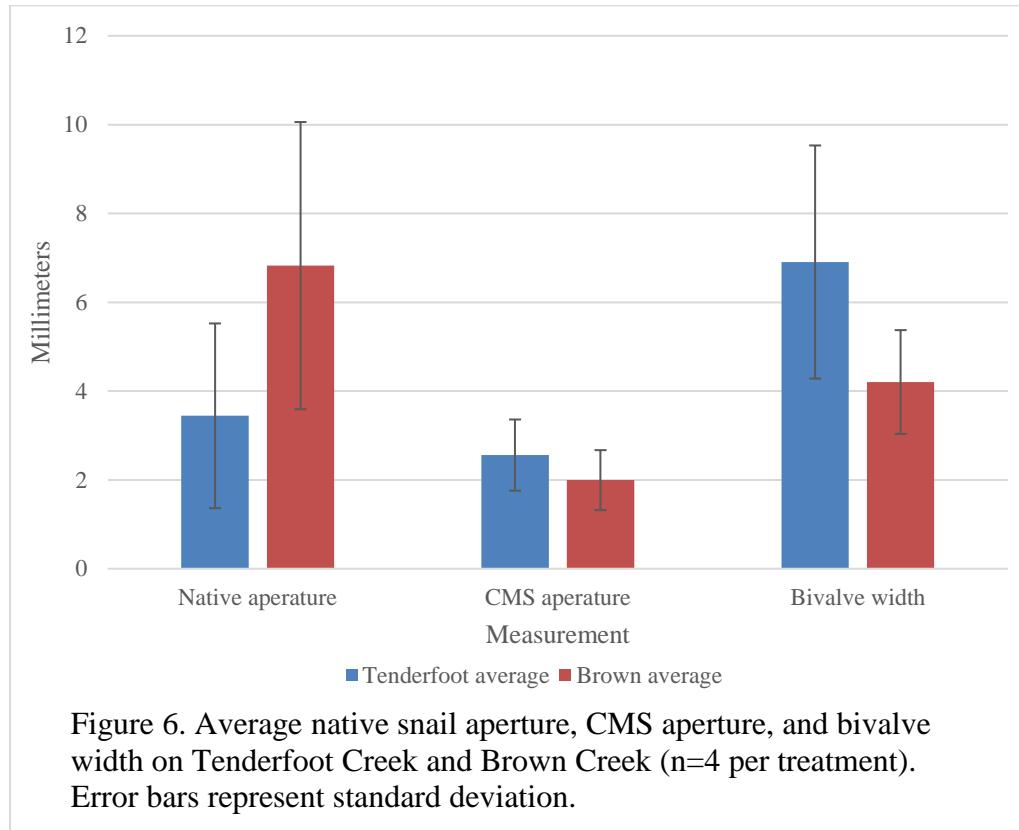


Figure 5. Average population count per invertebrate type for both uncaged zones and control cages on both creeks sampled during Week 4 (n=4 per treatment). Error bars represent standard deviation.



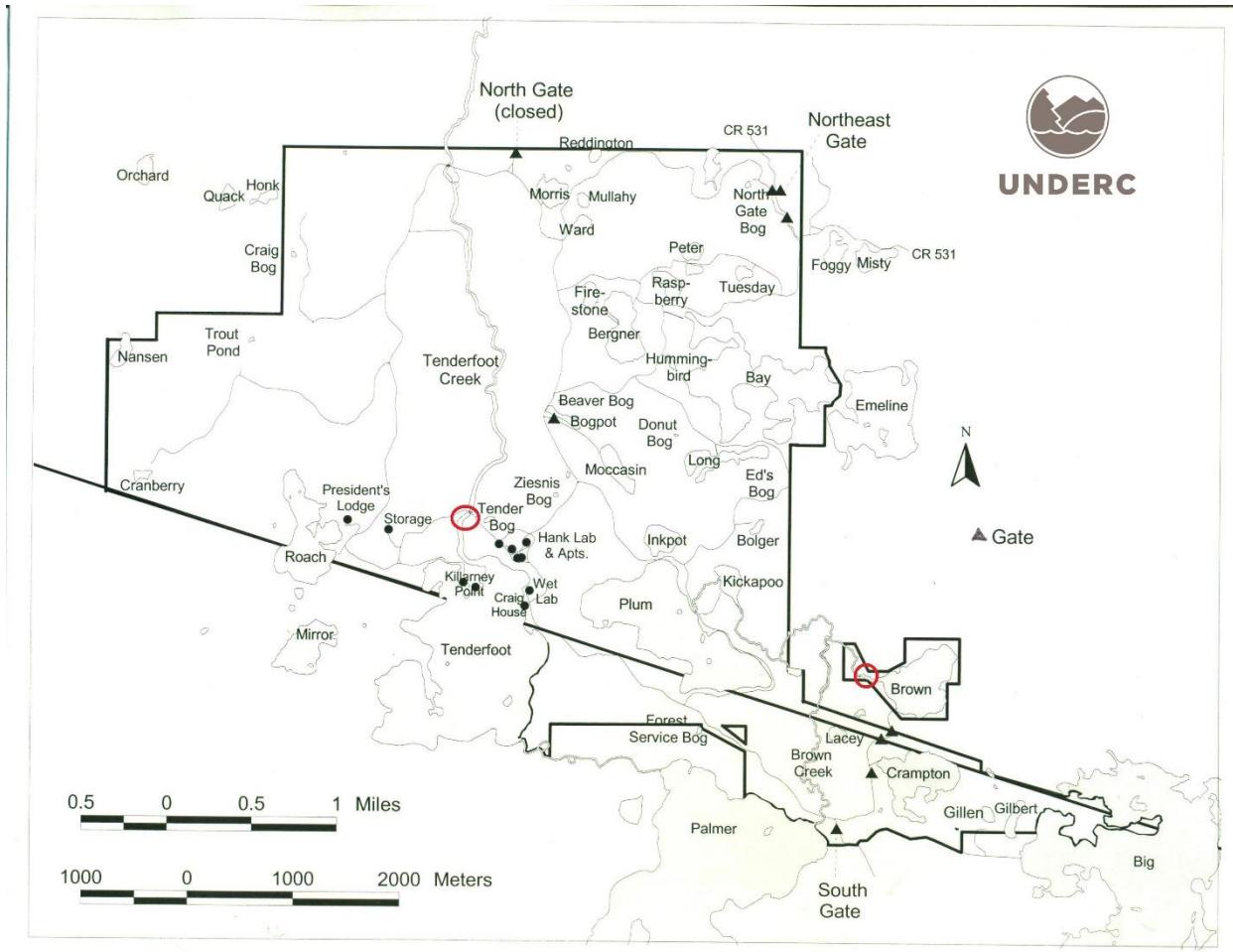


Figure 7. The locations on Tenderfoot Creek and Brown Creek where cages were erected.

UNDERC East Property Map. Retrieved from

https://underc.nd.edu/assets/175197/property_map.pdf. Edited by author.

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