Final Report

The Control of Asian clam (*Corbicula fluminea*) in Lake Tahoe with Benthic Barriers: The Influence of Water Temperature on Mortality

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Abstract

The Asian clam (*Corbicula fluminea*) is an invasive aquatic species that was first recorded in Lake Tahoe (CA-NV) in 2002. Since then, population densities have been recorded up to 8000 m^{-2}. *C. fluminea* are unique in their ability to withstand a wide range of environmental conditions, but are negatively impacted by hypoxia and anoxia. Prior research under warm water (> 15°C) conditions has shown that clams underneath EDPM rubber bottom barriers experience 100% mortality after 28 days. This study assessed the results for clam mortality under cold water conditions (4-10°C) in Marla Bay, Lake Tahoe during the winter, cold water period. Four experimental treatments were deployed, consisting of three 9 m^2 ethylene propylene diene monomer (EPDM), 45 mil thick barriers and a control plot. Macroinvertebrate data were collected from underneath the barriers using handcores, and DO and temperature data were monitored throughout the experiments. Control and experimental treatment sites had comparable macroinvertebrate species composition (dominated by dominated by *Corbicula*, oligochaetes, and larval dipteral/chironomidae), with the exception of the higher dominance of gastropods/planorbids at the treatment sites. Results indicated that irrespective of water temperature, all of the cold-water experimental treatments produced anoxic conditions under the rubber barriers, usually in less than 1 day. Results indicated that clams would eventually experience mortality in cold-water conditions (given that the under-barrier DO levels were fully depleted), but that time to mortality took longer as clam physiology slowed with decreasing temperature. At the coldest water temperatures, time to clam mortality took between 39 and 91 days. At average temperatures of 8-10°C it took longer than 43-47 days to achieve 100% clam mortality. Conservatively, to induce 100% Asian clam mortality rubber bottom barriers should be deployed for ~90 days, when water temperatures are below 10°C. We estimated that over the course of an entire year, barriers could be deployed in different locations up to six times. During cold-water conditions they would be deployed for three month periods (January-March, April-June, and October-December), and during warmer water conditions (July, August, and September) they could be deployed for one month periods. The less conservative management assumption is when water temperature is on the order of 10°C or less that total clam mortality would occur in 60 days. This assumption would allow an additional barrier treatment to be deployed for a total of seven treatments over the course of a year.

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1. Introduction

The Asian clam (*Corbicula fluminea*) was first introduced to North America in 1924 and to Europe in the 1980's, and has since become one of the most aggressive aquatic invasive species in western waterways (Counts 1986, Ortmann and Grieshaber 2003, Sousa *et al.* 2008). *C. fluminea* was first recorded in Lake Tahoe, CA-NV in 2002 and has since developed some of the highest density populations recorded (up to 8000 m^{-2}). In Lake Tahoe, *C. fluminea* are negatively impacting native species, aesthetic values of the nearshore, and are associated with accelerated growth of filamentous algal species (*Cladophora glomerata, Zygnema sp.*) and bacteria. The invasion is in a rapid population expansion phase, showing localized growth, as well as the establishment of new satellite colonies in nearshore areas separate from founder populations.

C. fluminea are unique in their ability to withstand a wide range of environmental conditions (largely due to valve closure), but research on the physiological tolerance of *C. fluminea* suggests an effect of anaerobiosis (lack of oxygen) on life history and growth. *C. fluminea* cannot maintain normal O_2 uptake under severely hypoxic conditions ($PO_2 \leq 5$ Torr, Johnson and McMahon 1998, McMahon 1999) and thus are typically restricted to shallow well oxygenated habitats. In contrast, many native clams (*Pisidium* spp.) are extreme O_2 regulators (Burky 1983) allowing them to inhabit highly hypoxic and hypolimnetic habitats. Depending on temperature conditions, *C. fluminea* may remain anaerobic with the valves shut for a minimum of 3–4 days at high temperatures and for several weeks at low temperatures (Mathews and McMahon 1999). It is only when the accumulation of toxic anaerobic end products (acetate, propionate, succinate) (Grieshaber *et al.* 1994) cause clams to open valves, move water over gills to eliminate end products and resume aerobic gas exchange that the clams are affected by environmental conditions, e.g. anoxia, biocides, toxicants (McMahon and Lutey 1988, Mattice *et al.* 1982, Jenner 1990).

Based on regulatory constraints and the preference not to use biocides, a non-chemical experimental control method was tested in Lake Tahoe to reduce *C. fluminea* populations. Lake Tahoe is a federally protected waterway where the application of pesticides or other non-natural chemicals is restricted (TERC 2011). Experimental treatment plots, using ethylene propylene diene monomer (EPDM) rubber pond liner as a bottom barrier, were applied at a depth of approximately 5 m in Lake Tahoe. The treatment areas were located within the dense clam beds located in the southeast portion of the lake (see below). Benthic barrier application in the warmer summer months (August-September, 2009) resulted in 100% *C. fluminea* and 70-95% benthic macroinvertebrate mortality after a 28-day period (Wittmann *et al.* submitted). Asian clams began to suffer mortality by day 7, significant death was seen by day 14, and complete mortality occurred between days 21 and 28. The range in ambient lake temperature at the 5 m depth was 15-20°C with an average of 17-18°C over the course of the experiment. These experiments demonstrated that under these high water temperatures for Lake Tahoe, prolonged exposure to extreme hypoxia resulted in complete *C. fluminea* mortality (Wittmann *et al.* submitted).

Although the warm-water experiments were successful in inducing clam mortality, the impact of colder water temperatures (10°C or lower) has not been studied in the field; yet if successful it could provide managers with an extended annual window for treatment beyond just the few warm summer months. Matthews and McMahon (1999) demonstrated in the laboratory that under hypoxic conditions, Asian clams survived without mortality for 84 days at 5°C, as compared to a mean of 11.8 and 35.1 days at 25°C and 15°C, respectively. These results indicate that winter mortality of clams in Lake Tahoe should be lower as compared to summer, since water temperatures impact clam physiology and mortality.

Based on these considerations, the purpose of this study was to assess the results for clam mortality under cold water conditions (4-10°C) using rubber bottom barriers, and compare those results to those obtained from warm water conditions (15-20°C) (see Wittmann *et al.* submitted, DRAFT Final Report for Asian clam Pilot Project, for the warm water component of this experiment). More specifically, the objectives of the current study were to:

1. Measure the rate of dissolved oxygen reduction under the rubber bottom barriers during cold water conditions.

2. Determine Asian clam mortality when covered with barriers during lake temperatures of 4-10°C.
3. Investigate the patterns of vertical distribution during the time course of hypoxia and anoxia.
4. Provide recommendations to the Lake Tahoe Asian Clam Working Group regarding length of rubber barrier deployment during both warm water and cold water conditions, and to provide a preliminary estimate for the number of treatment periods available on an annual basis.

2. Site Description and Methodology

Background on Lake Tahoe

Lake Tahoe is an oligotrophic lake located in the Sierra Nevada mountain range between California and Nevada at an elevation of 1898 m. The Tahoe basin's largely granitic geology, the lake's large volume and relatively small drainage explain the low nutrient concentrations and primary productivity. Increased development around the nearshore has resulted in a decline in water as evidenced by higher turbidity, increase growth of periphyton and other indicators (summarized by Reuter *et al.* 2009). Water temperature ranges between 5°C to 28°C in the littoral zone and lake temperatures are rising (S. Chandra, Aquatic Ecosystems Analysis Laboratory, University of Nevada Reno, unpublished data; Coats *et al.* 2006; TERC 2011).

Study Site

Experimental bottom barriers were applied in Marla Bay (Fig. 1), based on their successful deployment on previous occasions in Lake Tahoe (Wittmann *et al.* submitted; Wittmann and Allen unpublished observations/data). Marla Bay has a developed shoreline with residential and commercial structures, golf course, public beaches as well as recreational boater traffic. Marla Bay also has a shallow shelf that extends approximately 0.75 km from shore with an average water depth of 5 m. The sediment type in Marla Bay is coarse sand with a relatively diverse and abundant benthic macroinvertebrate community (26% *Corbicula fluminea*, 22% Gastropoda, 15% Oligocheata, 15% Ostracoda, 10% Diptera, 5% Amphipoda, 2% Pisidium, 1%

Nematoda, 4% other). Annual average *C. fluminea* density in 2009 in Marla Bay was 2270 (1217) m^{-2} and average density for all macroinvertebrates was 8841(805) m^{-2} (Wittmann *et al.* submitted).

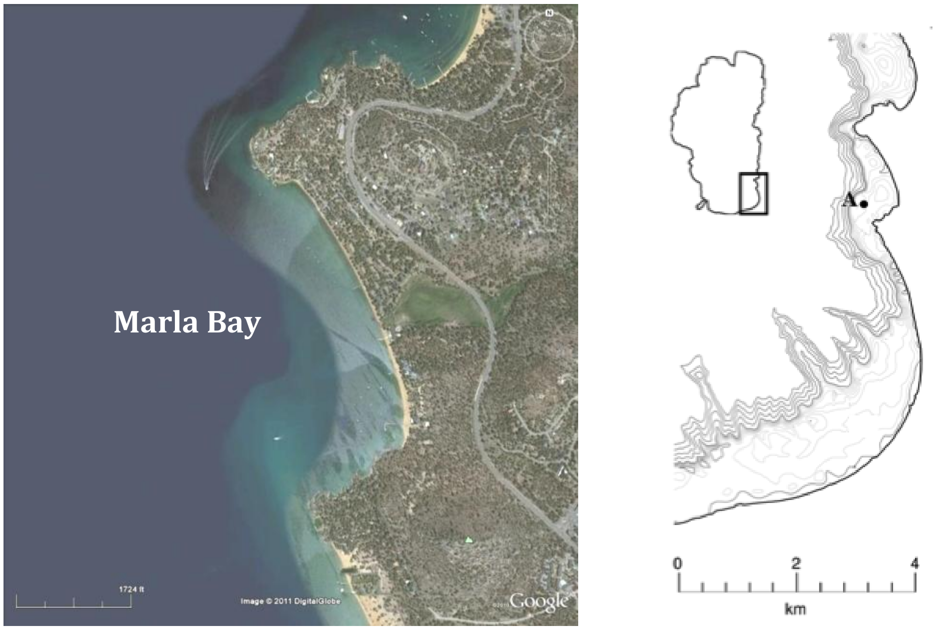

Figure 1. Location of bottom barrier deployments in Marla Bay (point A).

Experimental Design: Deployment of Bottom Barriers

A series of four Asian clam mortality experiments were conducted in Marla Bay during the winter, cold water period (4 to 10°C). For each experimental treatment, three 9 m^2, 45 mm thick EPDM barriers were deployed using 3 m long rebar rods as weighting to keep the sheets in place. Each treatment (i.e., three bottom barriers) was in place for a time period considered adequate to measure clam mortality. Since we hypothesized that clam mortality could differ significantly in the 4-10°C range of cold-water temperatures, it was the intended design of the experiment (and within the scope and funding) to run the treatments during a range of cold-water conditions. The experimental treatments were deployed in sequential order, such that after one treatment was concluded, triplicate bottom barriers were removed and moved to a new deployment area within Marla Bay. A total of four experimental treatments were conducted when water temperature was in the 4-10°C range. Both water temperature and dissolved oxygen (DO) were continuously monitored during each experiment (Zebra-Tech, Ltd. D-Opto Logger, Accuracy +/- 0.1°C for water temperature and 1% of the measured value for DO) to determine the loss of oxygen over time for treatments 2-4. During treatment 1, the DO probe was not available, so only water temperature at the bottom was measured.

Experimental Design: Macroinvertebrate Sampling, Taxonomic Identification and Data Analysis

Up to three individual hand-cores (45 cm length by 7 cm diameter PVC pipe) were collected under each of barriers at the end of the deployment time for each treatment, to characterize the benthic macroinvertebrate community. Additionally, 1-3 individual hand-cores were collected from an adjacent location not covered by the barriers (designated as the control site for each treatment). The sediment column in each hand-core was cut into 1 cm sections from the top down. Each of these sections was returned to the laboratory and preserved in 70% ethanol. Samples were analyzed for number and depth-distribution of *C. fluminea* and other macroinvertebrate species, using Thorp and Covich (1991) and Merritt and Cummins (1996). Individual *C. fluminea* were classified as living or dead based on either clam shell position (open shells indicated mortality) or strength of shell closure, i.e., mortality was indicated if it was possible to gently force the tip of a blunt dissection probe between the edge of the valves and cause the shell to open.

3. Results

Dissolved oxygen concentrations

Dissolved oxygen (DO) concentrations underneath the rubber bottom barriers were available for three of the four experimental treatments (Fig. 2, December 2010-June 2011). DO concentration data were corrected for drift using a detrending technique, and then corrected for offset (subtracting the median of the detrending) (MATLAB, v7.12). For experiment 2, DO concentrations beneath the rubber barriers took 3 days to drop to

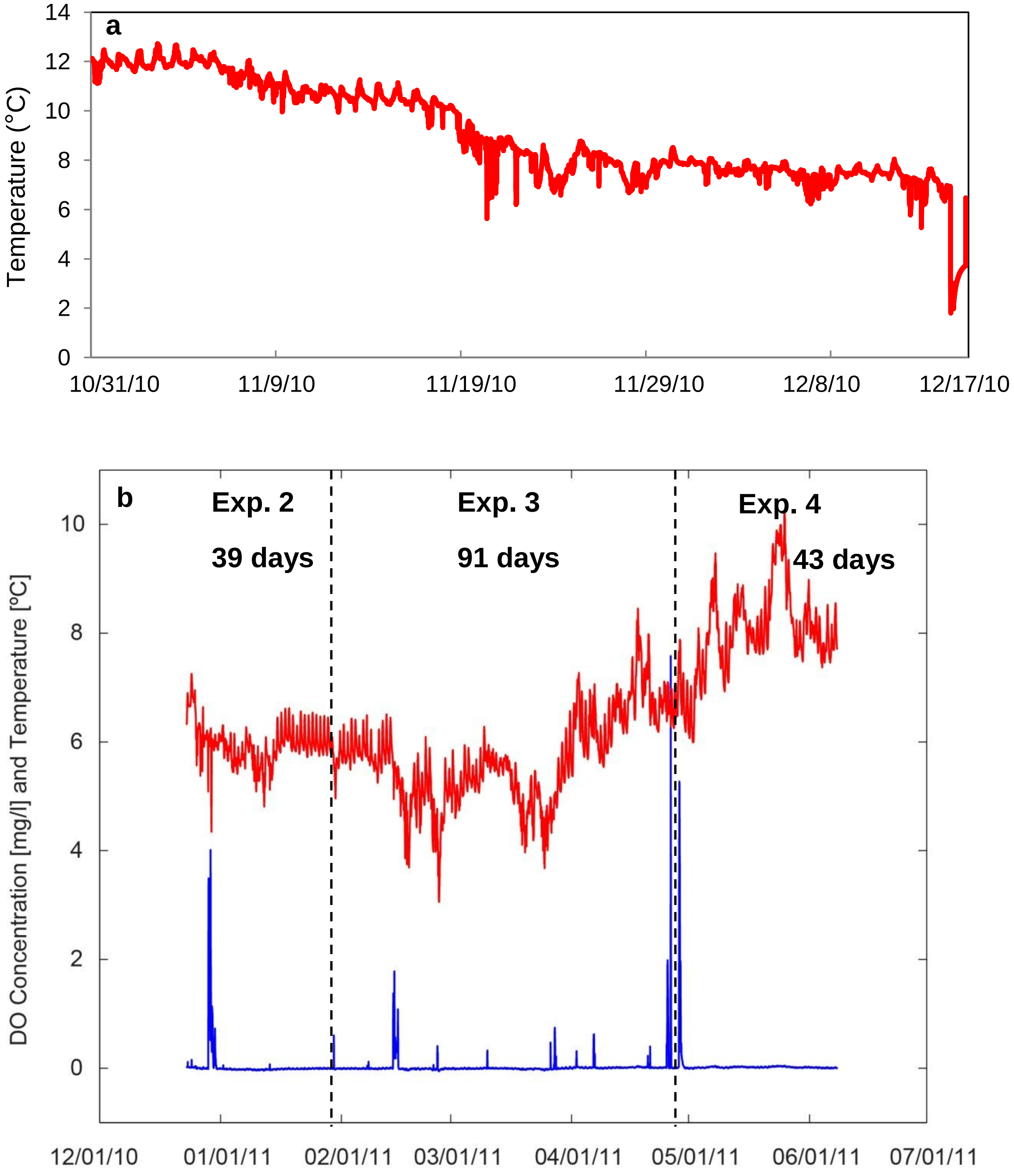

Figure 2. (A) Bottom water column temperature (°C, displayed in red) from October to December 2010, and (b) dissolved oxygen (mg/L, displayed in blue) and under-barrier temperature (°C, displayed in red) values collected from December 2010 to June 2011 in Marla Bay, over the course of three experimental treatments using rubber bottom barriers.

0%, or 0 PPM. It took less than 1 day for DO to reach 0 PPM during experiments 3 and 4. DO levels deviated noticeably from zero once over the course of experiment 2, on 12/29/10, where it took around 12 hours for DO levels to return to zero. DO levels rose noticeably above zero 8 times over the course of experiment 3, but the increases at the beginning and end of that experiment most likely reflect the movement of the rubber barriers and DO probe to their new location. The biggest spike in DO occurred on 2/14/11 and took almost 10 hours to return to zero. The other DO spikes took less than 4 hours to return to zero. After an initial spike in DO (again probably due to movement of the rubber barriers during experiment set-up), levels in experiment 4 were consistently zero, with no spikes.

Asian Clam distribution and mortality

Experiment 1

The average hand-core depth for all experiments was 18 cm, but the vast majority of clams were collected in sediment depths 7 cm or less. Experimental treatment one ran for 47 days, from 10/31/10 to 12/17/10. Three cores were collected from one rubber barrier and the control plot, and two cores were collected from the 2 other replicate rubber barriers. Water temperatures ranged between 5° and 12°C, with an average temperature of 9°C. Water temperatures were highest in October, and demonstrated a generally linear decrease over the course of the experiment, staying consistently below 10°C after 20 days. A small diurnal oscillation in water temperature was also present. Comparisons between bottom water temperature from Marla Bay and a rubber barrier deployed in the same area during October 2010 showed that the average difference between water under the barrier and above the barrier was 0.4°C ±0.6°C (TERC, unpublished data). In experiment 1, all of the clams collected from the control plot were alive, indicating 0% mortality in the area not treated with the rubber bottom barrier (Table 1). At almost all depths under the barriers, clam mortality rates were 100% (Table 1). There were two exceptions at deeper sediment depths (3 and 5 cm in a single core), where clam mortality was only 50%. The majority of clams (60%) were collected within the top two cm of the sediment column.

Table 1. Percent mortality of *Corbicula,* calculated as the percentage of dead:total (live + dead) clams. Data were collected from hand cores collected underneath rubber barriers (MB 1-3, average of 3-9 handcores) and from control sites (MBC, average of 3 handcores) during four time periods (October-June) in Marla Bay. Water temperatures ranged between 4 and 12°C. Empty cells indicate that *Corbicula* was not present in that sample. While isolated, individual clams were observed at certain depths below 7 cm, but their contribution to total numbers were negligible.

	Exp. 1, 47 days		**Exp. 2, 39 days**		**Exp. 3, 91 days**		**Exp. 4, 43 days**	
Sediment Depth (cm)	Mean MB1-3	Mean MBC	Mean MB1-3	Mean MBC	Mean MB1-3	Mean MBC	Mean MB1-3	Mean MBC
0	100	0	31	0	100	0	61	0
1	100	0	0	0	100	0	71	0
2	100	0	0	0	100	0	0	0
3	50	0	0	0	100	0	100	
4	100	0	0	0	100			
5	50		0	0				
6			0					
7	100							

Experiment 2

Experimental treatment two ran for 39 days, from 12/17/10 to 1/25/11. Instantaneous water temperatures underneath the barrier ranged between 4° and 7°C, with an average temperature of 6°C (Fig. 2). Temperatures demonstrated an oscillating diel pattern, with peaks around 2pm. Temperatures were slightly higher in the first 8 days of the experiment, and then stabilized around 6°C for the remainder of the experiment. Two large dips (<5°C) occurred in temperature during the experiment, once on 12/29/10 and once on 1/12/11, corresponding to peaks in DO levels underneath the rubber barriers. Three hand-cores were collected from under one barrier and from the control plot. Two hand-cores were collected from one of the remaining rubber barriers, and 1 hand-core from the other. All of the hand cores collected from the control plot contained only live clams, indicating 0% clam mortality (Table 1); this was also seen in experimental treatment one. The majority of clams in the control plot (84%) were located at depths of 3-5 cm in the sediment. Dead clams were only found in the upper 0-1 cm of the hand-cores, but mortality was only 31%; note this was not complete mortality and still relatively low compared to the other experimental treatments. At depths 2 cm or greater, no mortality was observed and only live clams were seen. However, 89% of the clams were found in the top 2 cm of the sediment column. Treatment 2 was the least effective at inducing clam mortality.

Experiment 3

Experimental treatment three ran for 91 days, from 1/25/11 to 4/26/11. The duration of this experiment was longer than anticipated due to researcher injury and the subsequent inability to use SCUBA to safely conduct the data collection for the experiment. Water temperatures underneath the barrier ranged between 3 and 8.5°C, with an average temperature of 5.7°C (Fig. 2). Temperatures generally demonstrated an oscillating diel pattern with peaks around 2pm. Superimposed over the diel pattern was a broader pattern of nearly linear fluctuations with durations of approximately 1 month for each decrease or increase in temperature. Hand-cores were collected from each of the rubber barriers and from the control plot. All of the hand cores collected from all of the rubber barriers contained only dead clams, and there was little between-core variation in terms of dead clam numbers (Table 1). The majority of clams (91%) under the barriers were found in 1 cm or less of sediment. Clam mortality under the rubber barriers was 100%, irrespective of sediment depth. Clam mortality in the control plot was 0%, and 75% of the clams in the control plot were found at sediment depths of 2-3 cm.

Experiment 4

Experimental treatment four ran for 43 days, from 4/26/11 – 6/8/11. Water temperatures underneath the barrier ranged between 6 and 10°C, with an average temperature of 7.8°C (Fig. 2). Temperatures conformed closely to an oscillating diel pattern, with peaks around 2pm. Temperatures also showed a relatively linear increase over the duration of the experiment until the end of May, when temperatures decreased by ~2°C and stabilized around 8°C. Three hand-cores were collected from each of the rubber barriers and from the control plot. All of the hand cores collected from the control plot contained only live clams, indicating no mortality (Table 1). Seventy-six percent of the clams in the control plot were collected in the top two cm of sediment. The majority of the hand-cores collected from underneath the rubber barriers contained both live and dead clams, with 88% of the density located in the upper 1 cm. Clam mortality underneath the rubber barriers ranged between 0% (3 cm sediment depth) to 100% (4 cm sediment depth). The top two layers of the sediment had average mortality rates of 61 and 71%, respectively, and three of the four depths where clams were found had >60% mortality.

Co-occurring benthic macroinvertebrates

The majority of the experimental sites in Marla Bay were dominated (based on live invertebrates only) by *Corbicula*, oligochaetes, gastropods, and larval dipteral/chironomidae (Fig. 3). The longer experimental treatments had lower levels of live *Corbicula,* but high levels of dead *Corbicula*. The control sites were dominated by *Corbicula*, oligochaetes, and larval dipteral/chironomidae. Larval chironomidae/diptera, oligochaetes, and gastropoda/planorbidae were the only species collected at all of the treatment and control sites. Mortality was measured for selected non-target invertebrate species (Lymnaeidae, Physidae, Gastropoda/Planorbidae, Trichoptera, and Pisidium spp.). Based on percent mortality, bottom barrier treatments had collateral negative impacts on all co-occurring non-target invertebrate species (Table 2). Gastropods collected from underneath the rubber barriers had high mortality ≥80% for 3 of the 4 experiments, but also had high mortality in control sites during January and April (Experiments 1 and 4). The native clam species *Pisidium* were only found underneath the rubber barriers and not in the control plots. Native clam mortality was 100%. Mortality for Lymnaeidae and Physidae was 100% while under the rubber barriers, and 0% in the control plots (Lymnaeidae only). Trichoptera mortality was high (≥90%) in both the control and treatment plots for Experiment 1, 29% in Experiment 2 (treatment plots only), and 0 in Experiment 4 (control only).

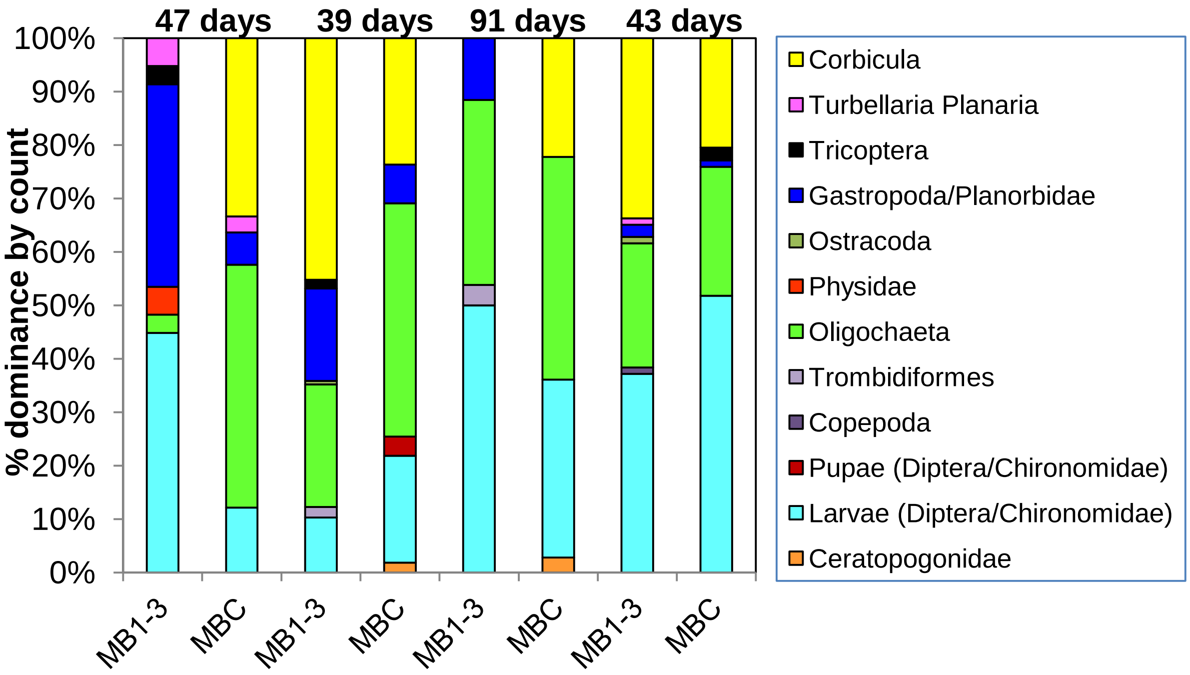

Figure 3. Invertebrate species composition for each set of barrier treatments (MB 1-3, for 47, 39, 91, and 43 days of barrier deployment time, respectively) and at control sites (MBC) in Marla Bay. Data represent live invertebrates only, and dominance was calculated based on counts per species from hand-core sampling.

Table 2. Mean percent mortality of selected non-target invertebrate species. Percent mortality was calculated from # dead compared to total collected. Empty cells indicate that a species was not collected at that time. Data were collected from hand cores collected underneath rubber barriers (MB 1-3, average of 3-9 handcores) and from control sites (MBC, average of 3 handcores) during four time periods (October-June) in Marla Bay. Water temperatures ranged between 4 and 12°C.

	47 days		**39 days**		**91 days**		**43 days**	
Invertebrate species	MB 1-3	MBC	MB 1-3	MBC	MB 1-3	MBC	MB 1-3	MBC
Lymnaeidae	100				100		100	0
Physidae	100							
Gastropoda/Planorbidae	80	0	47	33	85	100	88	0
Trichoptera	90	100	29					0
Pisidium spp.	100						100	

4. Discussion

Water temperature can impact the amount of time that an Asian clam can tolerate anaerobiosis (and thus maintain valve closure), as well as the evolution of high concentrations of harmful nutrients to benthic macroinvertebrates such as ammonia (Cooper *et al.* 2005) created in the barrier environment. With the exception of the Lake

Tahoe warm and cold-water experiments (Wittmann *et al.* submitted; this study), the impact of water temperatures and anoxia on clam mortality had not been tested in the field. Prior work has demonstrated that, in the lab, *Corbicula* survivorship decreases both with increasing temperature and decreasing oxygen concentrations. Johnson and McMahon (1998) examined Asian clam mortalities under hypoxic conditions ($PO_2 \leq 7.9$ Torr, 5% saturation), and found that total mortality occurred at 17 and 24 days at 25°C and 15°C, respectively, and at 34 days at 5 °C. However, a more recent study (Matthews and McMahon 1999) demonstrated that under extremely hypoxic (PO_2 <5 Torr, 2-3% saturation) laboratory conditions, Asian clams survived much longer (84 days) at 5°C, and found a mean of 11.8 and 35.1 days at 25°C and 15°C, respectively. In Lake Tahoe, Wittmann *et al.* (submitted) found that at an average of 18°C, it took approximately 14-21 days to reach conditions of near-complete mortality for Asian clams and 28 days for 100% mortality, under nearly anoxic conditions (DO ~ 0 mg/L). Therefore, the expectation for this study was that the time required for clam mortality would be longer with cold temperatures.

The results indicate that irrespective of water temperature, all of the cold-water experimental treatments produced anoxic conditions under the rubber barriers in Marla Bay. Anoxic conditions were produced rapidly, usually in less than 1 day. However, there were several occasions over the course of all of the experiments when DO levels rose above zero. These occasions tended to be linked to extremely low temperatures, and are theorized to reflect the influence of intense storms and currents on the conditions under the rubber barriers. DO levels under the barriers usually returned to anoxic levels within several hours. The results also indicated that the temperature difference between the temperature of the water column and the temperature underneath the mats was extremely low, allowing the use of either sets of data to describe under-barrier conditions.

Although anoxic conditions were present underneath the rubber barriers, the time necessary to achieve clam mortality appeared to be temperature dependent. The results indicated that clams would eventually experience mortality in cold-water conditions (given that barrier DO levels were fully depleted), but that total mortality took longer as clam physiology slowed down with decreasing temperature. At the coldest water temperatures, clam mortality took between 39 and 91 days (experiments 2, 3). These results are very consistent with the lab results of Matthews and McMahon (85 days at 5°C, 1999). At average temperatures of 8-10°C (experiments 1, 4) it took >43-47 days to achieve 100% clam mortality, but perhaps not many more since morality both of these experiments were high, if not complete. Clams underneath the barriers, both alive and dead, tended to be located in the uppermost layers of sediment, usually in 1 cm or less of sediment depths. It was beyond the scope of this experiment to determine if the clams classified as alive were experiencing stress that would have eventually lead to mortality. In comparison to the experimental treatments, no dead clams were collected from the control plots. Clams from the control plots tended to have a broader vertical distribution in the sediment than clams from underneath the barriers, and often the highest numbers of clams in the control plots were observed at sediment depths of 3-5 cm.

Control and experimental treatment sites had comparable macroinvertebrate species composition, with the exception of the higher dominance of gastropods and planorbids at the treatment sites. This was especially prominent for experiments 1 and 3, where *Corbicula* mortality was high. One possible explanation for this result is that the removal of *Corbicula* (via mortality) from under those bottom barriers removed the competitive effect of on native snail species, allowing their populations to expand in a manner that was not possible in the control plots. A side-effect of rubber barrier treatments was that some non-targeted benthic invertebrate species, primarily gastropods and native clam species, also experienced mortality. However, the extent of the mortality was lower than in the warm water rubber barrier deployments in Marla Bay, (Wittmann *et al.* submitted). The cold water conditions present in this study may have mitigated the impact of rubber bottom barriers on some macroinvertebrate genera, indicating a potential side benefit to barrier deployment in cold water conditions, as compared to warm water ones. Native unionid bivalves generally have temperature tolerances that are higher than *C. fluminea* over similar latitudes (McMahon 2002).

Management recommendations

The cold-water barrier experiments indicate that, conservatively, to induce 100% Asian clam mortality rubber bottom barriers should be deployed for ~90 days, when water temperatures are below 10°C. This conservative estimate is specifically based on the results of experiment 3; however, it is likely that 100% mortality was reached prior to day 91. Based on (1) this conservative treatment strategy (90 days when temperature is ≤10°C), (2) the results of the warm water experiment (Wittmann *et al.* submitted), and (3) water temperature from nearshore waters in Crystal Bay, NV from 2010 (S. Chandra, Aquatic Ecosystems Analysis Laboratory, University of Nevada Reno) we estimated that over the course of an entire year, barriers could be deployed six times. These deployments could occur three times in the summer and three times during the remainder of the year (see Fig. 4a). Barriers could be installed during cold-water conditions in January-March, April-June, and October-December, and for shorter, one-month periods of time in warmer water conditions (July, August, and September).

The less conservative management assumption is when water temperature is on the order of 10°C or less that total clam mortality would occur in 60 days. This assumption would allow an additional barrier treatment to be deployed for a total of seven treatments over the course of a year (Fig. 4b). Less conservative estimates are based on the fact that Asian clam mortality was noticeable, but not 100%, under barriers that were deployed for 47 days. Since research has demonstrated that time to clam mortality (in the lab) is much lower at 15°C (35 days, Matthews and McMahon 1999), it is possible that clam mortality in the field, under temperatures ranging between 10-15°C, would take less than 60 days, probably between 28-47 days. This would allow for an addition barrier treatment to be deployed over the course of the year, bringing the total to 8 treatments per year. However, this assumption should be tested in the field prior to use as a management technique. Future research should also establish the whether the less conservative or more conservative barrier deployment time is more accurate.

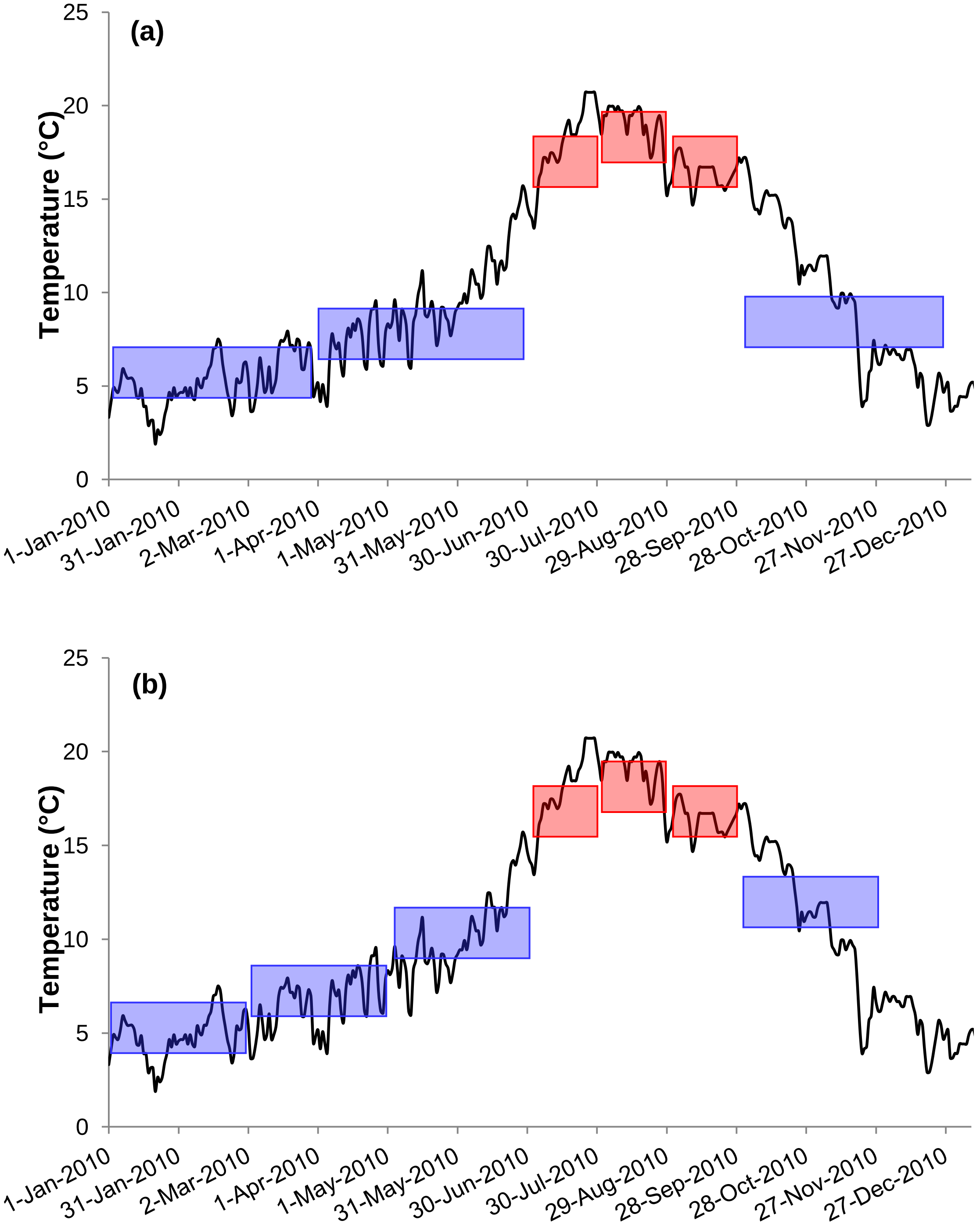

Figure 4. Recommendations for potential barrier deployment times based on a conservative (a) and less conservative (b) treatment scheme, based on nearshore temperatures from 2010. Blue boxes represent barrier deployment during cold-water periods (< 15°C), and red boxes represent barrier deployment during warm-water periods (<15°C). Temperature data come from Crystal Bay from water depths ranging from 0.75 to 1 m (S.Chandra, Aquatic Ecosystems Analysis Laboratory, University of Nevada Reno). Red boxes represent 28 days, blue boxes represent either 90 days (a), or 60 days (b) of barrier treatment time.

5. References

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