Effectiveness of Asian Clams (*Corbicula fluminea*) in Mitigation of Freshwater Eutrophication with Microcosm Approach

Junting Liang

ABSTRACT

Freshwater eutrophication degrades water quality and poses severe harm to ecological and human health. Bivalves are filter feeders that could be used for controlling the algae blooms associated with eutrophication by grazing on the phytoplankton and removing excess nutrients. This study conducted two laboratory microcosm experiments to investigate the capability of a widely spread bivalve, the Asian clam (*Corbicula fluminea*), to remediate freshwater eutrophication. The water was collected from two natural lakes. By the end of the first experiment, the values of turbidity, nitrate, ammonium nitrogen, and phosphate were significantly lower than the controls for water from both lakes, indicating a remarkable improvement of water quality by the stock of the Asian clams. The Asian clams displayed no differentiated performance in eutrophication mitigation between the two types of water since the trends of changes of the water parameters between measurements did not reflect inconsistency in distinct water bodies. In another experiment, the Asian clams' ability to tackle eutrophication was tested across three volumes of water. The result indicated that the Asian clams were fully capable to bear a remediation load of 5L to 6.7L water per individual and implied a considerably larger threshold volume for their mitigation capacity. Overall, under the selected conditions and densities, the Asian clams demonstrated their robust filtration capability to mitigate eutrophic water. With further complementing studies to obtain a more comprehensive understanding of their ecological functioning and impacts in freshwater ecosystem, it is plausible to develop a biotreatment solution of eutrophication based on the bivalve.

KEYWORDS

bivalve filtration; nutrient content; turbidity; water quality; bioremediation

INTRODUCTION

Algae blooms associated with eutrophication have become a prominent water pollution issue worldwide. Eutrophication is generally caused by extensive input of nutrients, especially nitrogen and phosphorus, which stimulates the phytoplankton biomass in the water body to grow to an abnormal level. Threats posed by such algae blooms to freshwater bodies include oxygen depletion, water quality degradation like high turbidity and unpleasant odor, biodiversity loss, and food web structure alteration (Moustaka-Gouni and Sommer 2020, Wang et al. 2016, Carpenter et al. 1999). While cutting down nutrient loading into the water bodies is a priority for controlling eutrophication, the ecological resilience within water ecosystem often delays the accomplishment of actual clear water. Excess nutrients accumulated previously in sediment, especially the phosphorus compounds, may still be released. Thus, additional approaches of eutrophication remediation are needed to reinforce the transition to clear water (Jeppesen et al. 2012). On the other hand, chemical treatment like the algaecides had previously been proposed as a solution to harmful algae blooms. However, algaecides cause environmental concerns since besides residual of the drugs themselves, lysis of the algae cells in this process often releases stored toxins into water body, which can harm the fish and birds (Silva et al. 2020, Carpenter et al. 1999). In response to these issues, scientists have turned to bioremediation to seek more efficient restoration tools of eutrophication.

Much research has shown that filter-feeding organisms may be effective in algae removal under appropriate water conditions. Generally, such organisms pass water through a specialized filtering structure in their feeding apparatus to trap the fine particles, organic materials, phytoplankton, and zooplanktons in the water column as food. Mechanical variations in specific filtering methods may present among different animal species, but the overall principle holds the same. Many filter feeders can help maintain the phytoplankton community composition and biomass at a healthy state to the ecosystem by consistently grazing on them. They allow desirable algae cells to produce the appropriate amount of oxygen and organic matters into water body (Mueller et al. 2004). Filter-feeding fish like silver carps, tilapia, and bighead carps possess considerable reliance on phytoplankton in their diet and can consume the algae directly to control their biomass (Wang et al. 2016, Lin et al. 2020). Many bivalve species including zebra mussels, blood clams, and Asian clams have also demonstrated remarkable filtration ability in water body. Besides the blooming algae, bivalves can remove suspended particles in water body as well. They transfer floating organic matters from water column into the sediment and thus reduce the excess nutrient concentration (Vaughn and Hoellein 2018). Nonetheless, filter feeders still exhibit different shortcomings on effectiveness in actual control of eutrophication and improvement of water quality because of their food selection and living habit. For instance, while consuming algae biomass, bighead carps were observed to produce excrement rich in phosphorus nutrients that enhance growth of the phytoplankton in return (Huang et al. 2016). For bivalves, the problem is that they usually prefer to feed on algae smaller than 20 micrometers, which leaves considerable portion of phytoplankton (Shen et al. 2020). The coexistence of both advantages and drawbacks contributes to the controversial results from previous studies about effect on controlling algae biomass and nutrient content by filter feeding organisms (Huang et al. 2016, Wang et al. 2016, Lukwambe et al. 2020, Lin et al. 2020).

The attempt to introduce filter feeders for eutrophication mitigation should be conducted on a context-dependent basis. The living and foraging habits of the filtering organisms could have varied consequences based on conditions in target water bodies (Sousa et al. 2009). In this paper, the focus falls on a widespread bivalve in many water ecosystems around the world: the Asian clam (*Corbicula fluminea*). It is a well-known invasive species in the United States and was thought to be brought to the Pacific coast by Chinese immigrants in the 1920s as a food resource. The Asian clam was later found present in South America and Europe in the 1970s (Sousa et al. 2008). The high filtration rate of the organism (Sousa et al. 2008, Silva et al. 2020) makes it suitable for an exploration of its effectiveness in remediating eutrophic freshwater bodies within a relatively short period. Considering the common presence of the Asian clam in rivers and lakes around the world, it is worthwhile to dig its potential for building a preliminary restoration method for eutrophic freshwater body.

Building on top of previous work, this paper intends to investigate the efficacy of eutrophication treatment by the Asian clams. Because of the context-based feature of the mitigation effort by filter feeders, to obtain a meaningful result, the study would be conducted with locally collected water from Lake Anza and Lake Temescal in Berkeley, California. Asian clams have been demonstrated by previous studies to be effective in algae removal and nutrient concentration control overall, but differentiated effects were reported for certain water parameters like the concentration of phosphorus compounds (Shen et al. 2020, Silva et al. 2020, Sousa et al. 2009). The study first investigated plainly the Asian clams' performance in eutrophication treatment in the collected water through one experiment. In the meantime, I made a comparison between the performance in the two types of lake water to understand if the bivalves' mitigation efficiency changes among the different water. The study proceeded with the water in which the clams worked more efficiently. A second experiment was then conducted to explore the Asian clams' efficiency in remediating different volumes of the selected lake water. Consequently, the greatest amount of water under current eutrophic level that the clams can effectively clean may be obtained. The result of the study may provide indicative information for the suitability of applying Asian clams to eutrophication remediation in water bodies of similar environmental properties and conditions.

METHODS

Study site and organisms

I conducted this study at UC Berkeley from March 16th to April 14th. The water used for this study were collected from Lake Anza and Lake Temescal in Berkeley, California. Both lakes are freshwater lake in the East Bay Regional Parks. Lake Anza is located at 37.89-degree North, 122.25-degree West, with an altitude of 242m. I collected water samples at the northwest shore. I used a filter to filter away the covering azolla on lake surface and large, suspended particles. Lake Temescal is located at 37.84-degree North, 122.23-degree West. The altitude is 132m. I collected water samples from the beach at northeast side of the lake. Lake Temescal did not have azolla covered, but a filter was still needed to get rid of large particles. In addition, I also collected sediment from shallow water region near shore of both lakes. Their containers were covered tightly all the time before running the experiment to maintain the original wetness.

I collected the Asian clams from an aquaculture pond. The selected individuals had healthy body condition with no obvious injuries. The average weight of the Asian clams was 5.22 ± 0.24g. The average shell size was 2.10 ± 0.3cm. I raised the clams in four 2.75-liter buckets with the collected water and sediment for a week as a quarantine. Water was changed every two days. This process allowed them to adapt to the water condition and get rid of potential pathogens and parasites from the previous pond (Shen et al. 2020, Silva et al. 2020).

Microcosms for experiment 1: treatment efficiency of Asian clams and performance across water bodies

To assess the mitigation efficiency of Asian clams, I built a set of microcosms up for each lake water. I used five-gallon food-grade buckets as the microcosms. They were made of polyethylene and had very low light penetration on side and bottom, which can better simulate a natural underwater environment. I filled 14L eutrophic water into each microcosm, with approximately 1.5cm of sediment sprayed evenly at the bottom. The initial biomass of Asian clams in each bucket was controlled at 16g to 18g, corresponding to three or four clams depending on the sizes. Each set of microcosms included four replicates and one control without clams. The lighting period followed a 16-hour daylight to 8-hour darkness pattern.

Water parameters and sample collection

To track the eutrophication level throughout the experiment, the water parameters I monitored included dissolved oxygen (DO), turbidity, chlorophyll a (chl a), nitrate, ammonium nitrogen (ammonium-N), and phosphate. Additionally, I recorded the temperature to ensure a constant condition among treatment groups during the experiment. The experiment ran for nine days. I measured DO and temperature daily directly from water with a DO meter. Turbidity was measured daily using a turbidity meter. In each measurement, I took a 250ml water sample from 10cm below surface and 5cm above sediment and mixed thoroughly. Then, I transferred

10ml of the water sample into a vial for turbidity measurement.

I conducted chl a and nutrient concentration measurements at the 1st, 5th, and 9th days during the experiment period. I sampled the water in the same way as above. For chl a, I took 50ml of mixed water from each microcosm for centrifugation and then used a spectrophotometer to test for concentration in the concentrated samples. I measured the nutrient concentrations with the corresponding semiquantitative test kits. After sample mixing, I took two 5ml samples for ammonium-N. A 2.5ml sample and a 5ml sample was used for nitrate and phosphate testing respectively according to the procedures of the test kits.

Data analysis for exploring treatment efficiency and performances across water bodies

Graph processing for water quality parameters

I took an average between the four replicates for the measurements to obtain nine data points for temperature, DO, and turbidity and three data points for chl a and nutrient concentrations. To visualize the trend of each parameter during the experiment period, I graphed its data against time in unit of day, along with the control trend for comparison.

Statistical analysis

I used an analysis of variance for repeated measurement (rANOVA) to explore the significance of mitigation for each water parameter between time points at the 1st, 5th, and 9th day. The alternative hypothesis was that the values obtained at each time point were different from that of the previous one. A significant change would support that there was an effective improvement of water quality in the time interval. I also used a two-sample t-test to test for the difference in percentage changes of each water parameter at each measurement for the two types of water. The mean changes should have statistically significant difference if the Asian clams performed differently between water bodies. I set the significance level at $p < 0.05$. I performed the statistical analysis in RStudio 4.0.2.

Microcosms for Experiment 2: Threshold volume of eutrophic water for effective purification

Based on the previous experiment, I selected the lake water where the clams showed advanced treatment performance to run experiment two. I set up microcosms filled with increasing water volumes: 10L, 15L, and 20L, and again sprayed the sediment evenly at 1.5cm thickness. Each volume had three replicates. As before, I put 16g-18g of Asian clams into each microcosm. In a 7-day period, I tracked the water parameters in the same way as the first experiment.

Data Analysis for exploring the threshold volume for mitigation

I graphed trends of the water parameters in the same manner as above experiment. I used an analysis of variance (ANOVA) to test for difference in mean percentage change of each water parameter between every measurement through the period among water volumes. The changes would display statistically significant difference if the Asian clams' treatment effectiveness varied across water volumes. As before, I used an analysis of variance for repeated measurement (rANOVA) to explore the changes of water parameters between time points at the 1st, 4th, and 7th day. I set the significance level at $p < 0.05$ and conducted the analysis in RStudio 4.0.2.

RESULTS

Experiment 1: Treatment efficiency among water bodies

Physical Water Parameters: DO, Turbidity, and Temperature

Plot of the temperature trend is shown in figure 1.1. The average temperature over the period was 20.34 ± 0.24 Celsius degree for Lake Temescal water and 20.38 ± 0.28 Celsius degree for Lake Anza water. No significant difference was detected in temperature among treatments during the experiment period ($p > 0.05$).

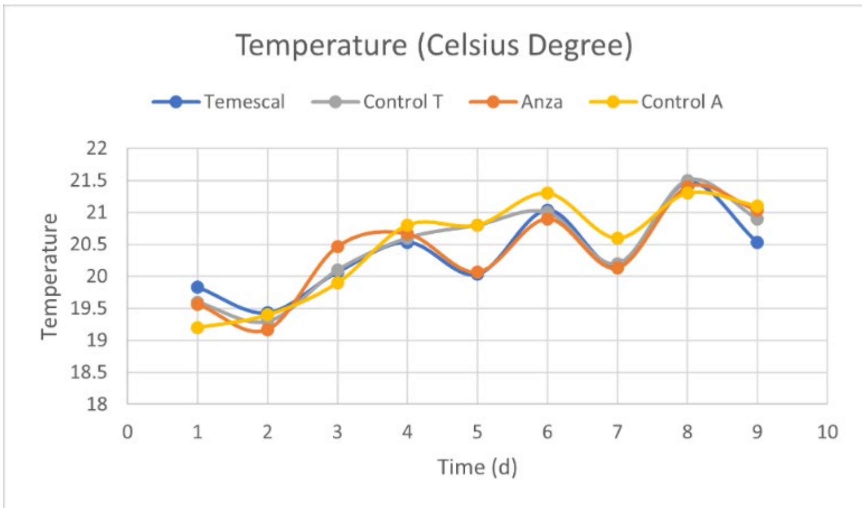


Figure 1.1. Trends of temperature of the two water groups. The graph shows temperature of the treatments in the 9-day experiment period together with the controls. The temperature in Celsius degree is on y-axis, while the time measured in day is on x-axis.

I plotted the trends of dissolved oxygen (DO) in both lake water in figures 1.2. The dissolved oxygen for both water bodies experienced an increase followed by a decrease. For Lake Anza water, the DO values rose by 8.1% through the first three days and then decreased by 5.9% through the fifth day. It fluctuated at a higher value than the control since then. Throughout the complete period the treatment groups had significantly higher DO values on average than the control ($p < 0.05$). For Lake Temescal water DO increased by 8.5% in three days; after that it dropped by 8.2% through the fifth day and fluctuated around the initial value for the rest of the period. On average DO in treatment groups was still higher than the Temescal control during the experiment ($p < 0.05$). On the other hand, there was no significant difference in mean percent changes of DO throughout the experiment between the two water bodies ($p > 0.05$).

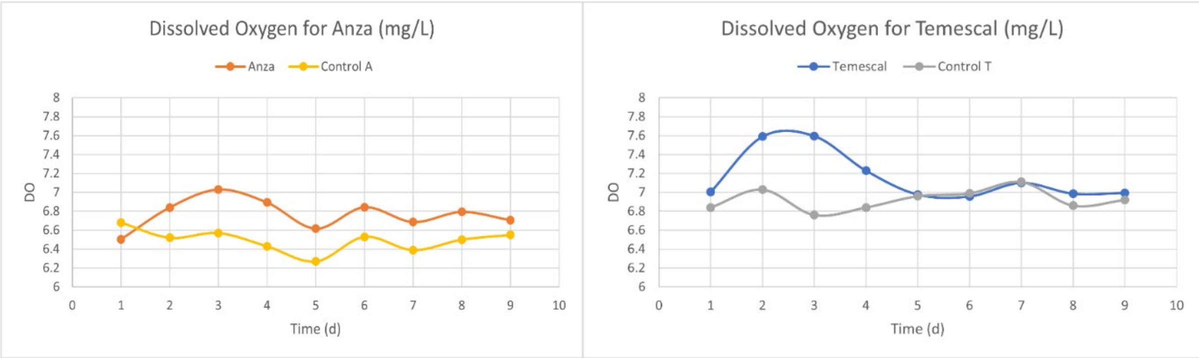


Figure 1.2. Trends of DO of the two water groups. The plots display the DO values during the experiment period in comparison to the control. The left graph shows DO for Lake Anza water and the right graph is for Lake Temescal water. On both plots, DO measured in mg/L is on y-axis and time in unit of day is on x-axis.

Changes in turbidity for the two water bodies over time were plotted in figure 1.3. Turbidity in both types of water had a significant response to the stock of Asian clams. In the Anza group, the decrease between the 1st, 5th, and the 9th days was significant ($F = 1850$, $p < 0.05$). The turbidity at the end of experiment was 67.5% lower than the Anza control. In Lake Temescal water, a significant drop was observed too between the same time points ($F = 1515$, $p < 0.05$). The final turbidity was 74.3% lower than the Temescal control. No significant difference in turbidity percent changes were observed between the two water bodies ($p > 0.05$).

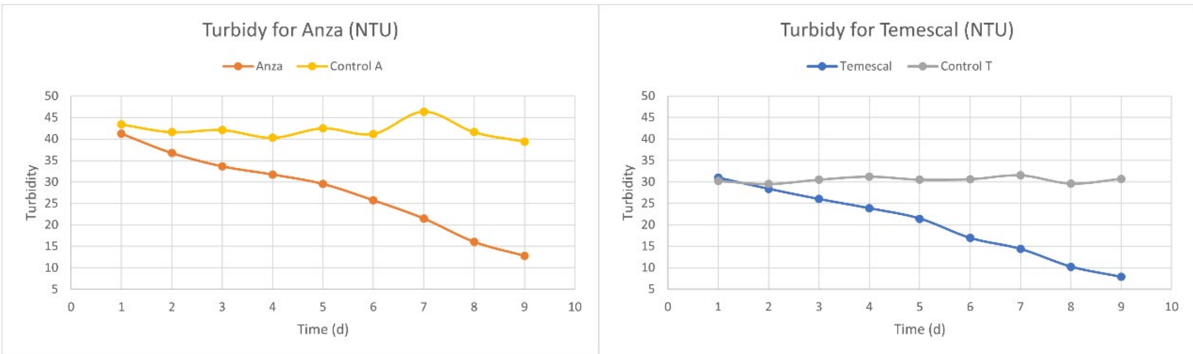


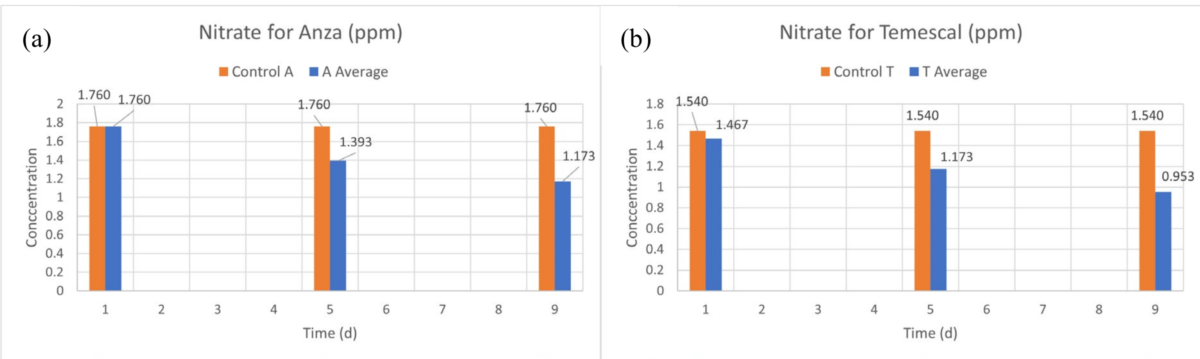
Figure 1.3. Trends of turbidity of the two water groups. The graphs show turbidity values of treatments through the 9-day period in comparison to the control. The left plot shows turbidity trend of Lake Anza group while the right one shows the trend of Lake Temescal group. Turbidity in NTU unit is on y-axis, against the time measured in day on x-axis.

Biological Water Parameters: Chlorophyll a concentration

The measurement of chlorophyll a was inconclusive for both water bodies. The results were negative numbers, meaning that the chl a concentration in the water samples were too low for the spectrophotometer to detect. The water quality report provided by the East Bay Regional Park suggested an on-site chlorophyll a concentration of 5.1 microgram/L for Lake Anza and 5 microgram/L for Lake Temescal. The values were out of the measurement range of the spectrophotometers accessible. Therefore, chlorophyll a was excluded from the consideration of eutrophication treatment efficiency in this project.

Chemical Water Parameters: Nitrate, Phosphate, and Ammonium Nitrogen

The trends of nitrate and phosphate concentrations for both lake water were displayed in figure 1.4. Significant responses to Asian clams' presence were observed for nitrate and phosphate. In Lake Anza water, there was a significant drop throughout the experiment for both nitrate and phosphate ($F = 54.6$, $p < 0.05$; $F = 88.2$, $p < 0.05$). At end of the experiment, nitrate and phosphate concentration was 33.3 % and 50% lower than the control respectively. A significant decrease in nitrate and phosphate was also observed in Lake Temescal water ($F = 61$, $p < 0.05$; $F = 18$, $p < 0.05$). Their final values were 38.1% and 33.3% lower than the Temescal control respectively. For both compounds, there was no significant difference detected in concentration percentage change between Anza water and Temescal water ($p < 0.05$).



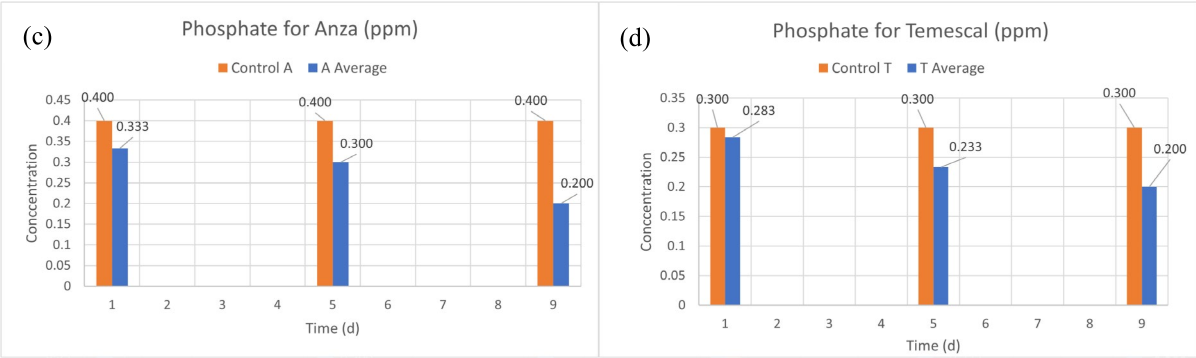


Figure 1.4. Trends of nitrate and phosphate of the two water bodies. The graphs display the values of nitrate and phosphate concentrations on the 1st, 5th, and 9th day of the experiment period: (a) nitrate of Anza water, (b) nitrate of Temescal water, (c) phosphate of Anza water, (d) phosphate of Temescal water. In all plots, the y-axis is concentration in ppm. The x-axis is time in day. The measurements from the control are also shown alongside for comparison.

For ammonium nitrogen, the final values for both lakes were already at the test kit's lowest testable value (0.13ppm). In Figure 1.5, these values were recorded as less than 0.13ppm. Ammonium nitrogen concentration for both lakes likely had experienced a significant decrease in the experiment period and reached a level significantly lower than the controls at the end, but this could not be confirmed through a statistical test.

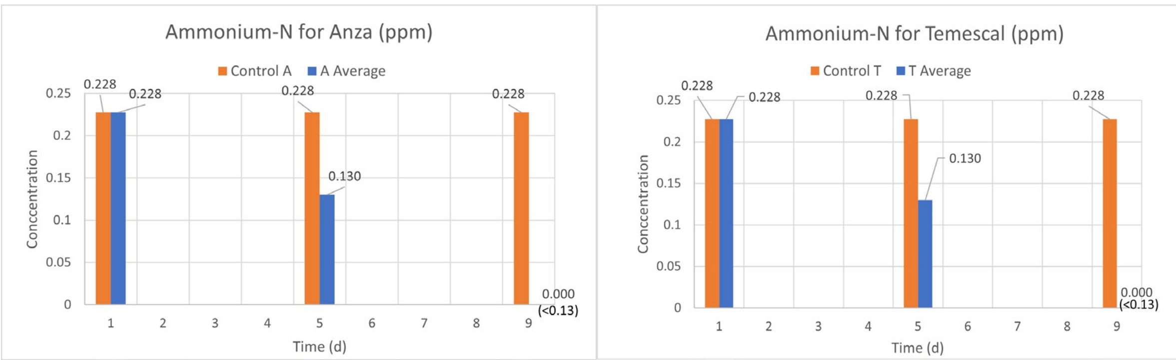


Figure 1.5. Trends of ammonium-N of the two water bodies. The plots show the concentration of ammonium nitrogen measured on days 1, 5, and 9. The left graph is ammonium-N concentration for Lake Anza water, while the right graph shows the measure for Lake Temescal water. Concentration in unit of ppm is on the y-axis. Time in unit of day is on the x-axis. The final values in treatment groups on both graphs are recorded as less than 0.13 ppm since the value was out of the lowest testable range of the ammonium-N test kit.

Experiment 2: Threshold water volume for efficient purification

Lake Anza water was used for this experiment because its higher initial values in turbidity and nutrient concentrations could potentially be more indicative in Asian clams' capability of eutrophication remediation.

Physical Water Parameters: DO, Turbidity, and Temperature

Temperature of all the water volumes were graphed in figure 2.1. Average temperature was 20.20 ± 0.54, 20.20 ± 0.64, and 20.4 ± 0.66 Celsius degree for 10L, 15L, and 20L groups respectively during the experiment. There was no significant temperature difference among volumes during in the experiment period ($F = 0.17$, $p > 0.05$).

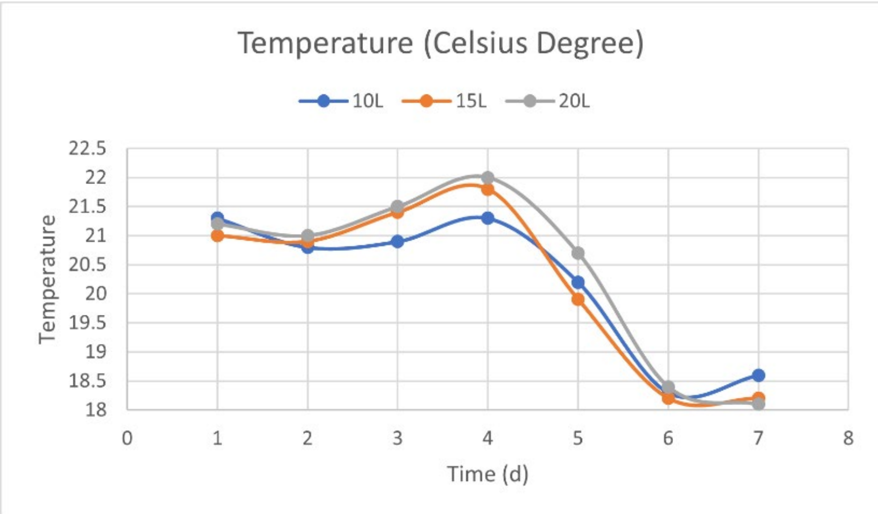


Figure 2.1. Trends of temperature across water volumes. The graph shows the temperature of three water volumes throughout the 7-day experiment period. Temperature in Celsius degree is on y-axis and time in day is on x-axis.

DO trends of all water volumes were plotted in figure 2.2. For the 15L group, the DO value increased through the first four days and decreased to a range close to the initial level in the rest of the period. The DO for 20L group increased through the initial three days. It fluctuated around a medium level compared to the other two groups since then. The final DO value was 3.5% higher than the initial. For the 10L group, DO only increased in the first day and then decreased to a significantly lower range than the other volumes. The final value was 3.7% lower than the initial. The mean DO through the experiment period was significantly different among the volumes ($F = 7.05$, $p < 0.05$). Nevertheless, no significant difference in DO percentage change was detected between the treatments ($F = 1.80$, $p > 0.05$).

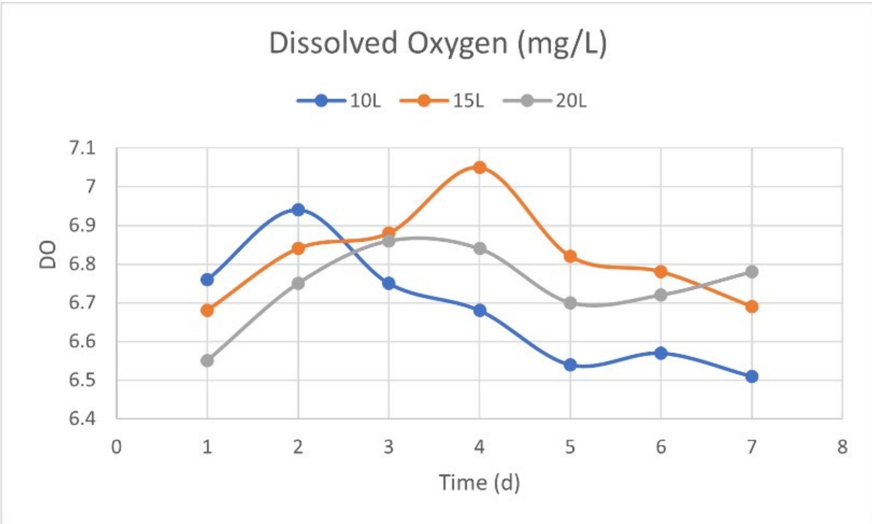


Figure 2.2. Trends of DO across water volumes. The plot is the DO values of the three volumes during the experiment period. The y-axis shows DO in mg/L, against the x-axis showing time in day.

Turbidity trends over time were plotted in figure 2.3. Significant responses to the stock of Asian clams were detected in all water volumes. Turbidity dropped by 40.4%, 50.5%, and 54.5% in the 10L, 15L, and 20L groups respectively. The turbidity difference between the time points (day 1, day 5, and day 7) were significant for all three groups ($F = 493$, $p < 0.05$; $F = 662$, $p < 0.05$; $F = 686$, $p < 0.05$). The mean percent change in turbidity through the period also had significant difference among the three volume groups ($F = 7.64$, $p < 0.05$).

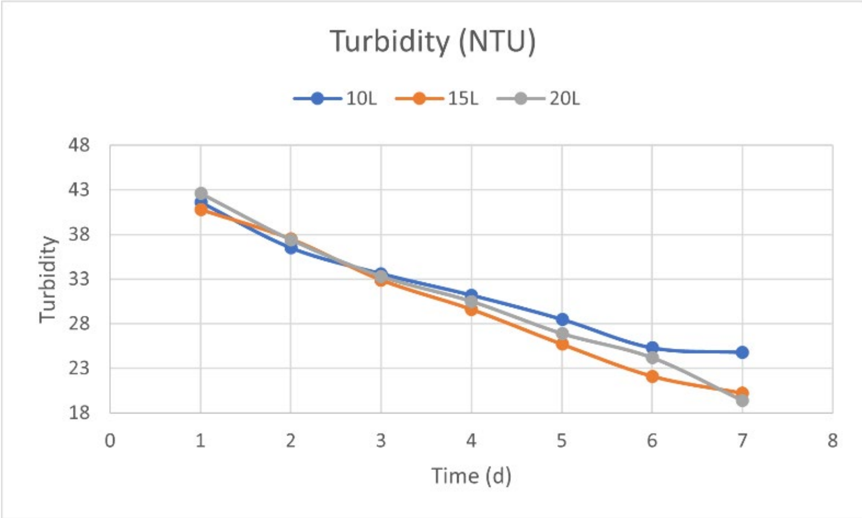


Figure 2.3. Turbidity trends across water volumes. The graph displays the values of turbidity in the three water volumes throughout the experiment. Turbidity is measured in NTU unit and corresponds to the y-axis. On x-axis it is time measured in unit of day.

Chemical Water Parameters: Nitrate, Phosphate, and Ammonium Nitrogen

All measurements of nitrate and phosphate concentrations for the three water volumes were shown in figure 2.4. For all three water volumes, nitrate concentration decreased significantly throughout the experiment ($F = 8.0$, $p < 0.05$; $F = 49$, $p < 0.05$; $F = 50$, $p < 0.05$). The nitrate concentration reduction was 12.5% for 10L, and 37.5% for the 15L and 20L groups. Significant difference was detected in mean percentage changes of nitrate among the volumes ($F = 6.03$, $p < 0.05$). Significant drop in Phosphate concentration through the period was observed in all three treatments as well ($F = 32$, $p < 0.05$; $F = 76$, $p < 0.05$; $F = 109$, $p < 0.05$). Phosphate concentration decreased by 42.9%, 42.9%, and 50% for 10L, 15L, and 20L respectively. There was no significant difference observed in mean percentage changes among volume groups though ($F = 2.06$, $p > 0.05$).

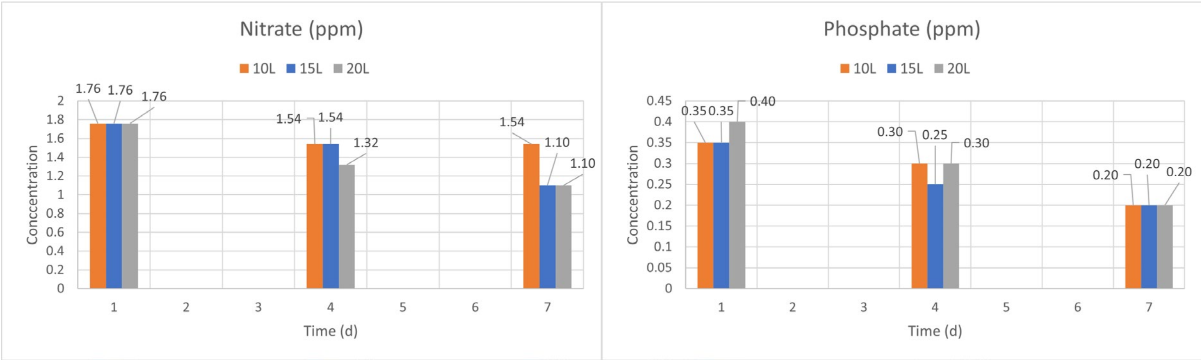


Figure 2.4. Trends of nitrate and phosphate across water volumes. The plot shows nitrate and phosphate concentrations of the three volumes on the 1st, 4th, and 7th day of experiment. Nitrate is on the left graph and phosphate is on the right one. Both graphs have concentration in unit of ppm on the y-axis and time in unit day on the x-axis.

Trends of ammonium-N concentration were displayed in figure 2.5. Only the 10L group had the final ammonium-N level within the testable range of the test kit (0.13ppm). The end value was 42.9% lower than the initial. The decrease between time points was significant ($F = 8.31$, $p < 0.05$). For the 15L and 20L groups, the end measurements were recorded as lower than 0.13ppm. It was likely that Ammonium nitrogen had decreased based on the observation, but the result couldn't be tested by a statistical method.

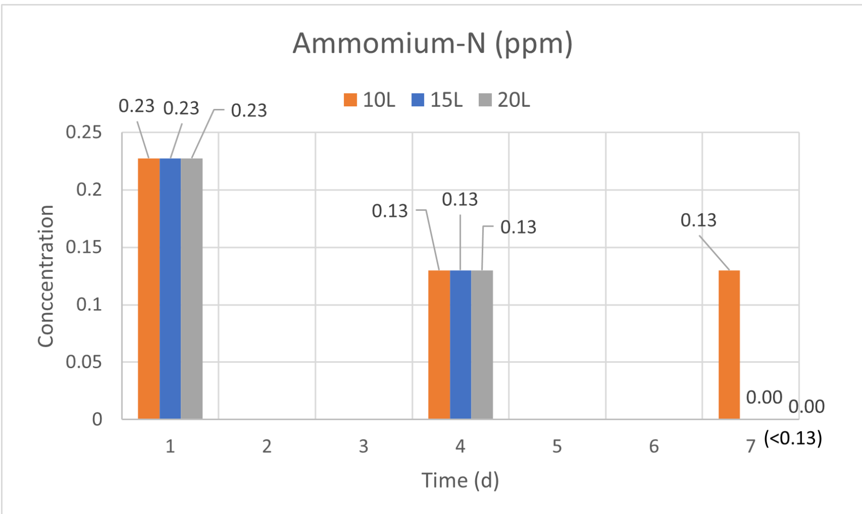


Figure 2.5. Trends of ammonium-N across water volumes. The graph displays the ammonium nitrogen values measured on days 1, 4, and 7. The y-axis is concentration in ppm and x-axis is time in day. The ammonium-N measurements at the end for the 15L and 20L groups are shown as less than 0.13 because they are lower than the

lowest testable value of the ammonium-N test kit.

DISCUSSION

The study intended to explore the efficiency of Asian clams (*Corbicula fluminea*) in freshwater eutrophication remediation. I ran two microcosm experiments. Experiment one directly investigated the Asian clams' capability to purify eutrophic water collected from Lake Anza and Lake Temescal in Berkeley, California. Meanwhile, I also compared the clams' performance between the two types of water to understand if the bivalve worked more efficiently in one water body than the other. I set up experiment two to study the performance of the Asian clams in three volumes of Lake Anza water and seek a maximum volume of water that the clams can effectively purify. Result of experiment one fitted my expectations that the Asian clams can effectively mitigate eutrophication by improving the water quality parameters in the collected lake water. Their performance did not vary between Lake Anza and Lake Temescal water. Result of experiment two suggested that the 16 to 18g of Asian clams, typically corresponding to three to four individuals, were fully capable of remediating 20L water from Lake Anza. These outcomes demonstrated the strong filtration capability of the Asian clams to deal with eutrophication. The organisms had the potential to act as the central part of a solution to freshwater eutrophication, though there were still gaps to be filled to obtain a comprehensive enough proposal.

Analysis of the Asian clams' performance within and cross water types

In experiment one, significant changes in all water quality parameters between the beginning, middle, and final time points during the experiment period were detected. The controls were maintained in same conditions as the treatments throughout the period except for the absence of clams in them. While all the water parameters displayed no significant changes in the control of both water types, there was obvious improvement in turbidity and concentrations of the three nutrients in all the treatments, suggesting the enhancement of water quality by the stock of Asian clams. The enhanced turbidity was consistent with the suggestions from previous studies over the use of bivalves to mitigate eutrophication. However, they obtained the result primarily through studying the decrease in algae biomass or shift in phytoplankton community, which were aspects not included in this study due to the limitation in equipment (Lukwambe et al. 2020, Sousa et al. 2009, Li et al 2010). The confirmable perspective from this study was that the clams' transfer of floating nitrogen and phosphorus particles into the sediment indeed helped improve clarity of the water column (Vaughn and Hoellein 2018). DO in Lake Anza was maintained at a level higher than the control. For Lake Temescal, although the DO mean through the period was significantly higher than the control, it was likely caused by the large rise and drop observed during the first four days. The DO level in the second half of the experiment was not significantly different from the control. Thus, such result can suggest that the clams might have risen the DO in Lake Anza water by a small amount, but their impacts on DO in Lake Temescal water was unclear.

The decrease in nitrate and ammonium also fitted the results obtained by previous studies, supporting that the Asian clams can reduce the nitrogenous nutrients available in water column to suppress algae growth (Li et al. 2010, Shen et al. 2020). For phosphate, though my study showed an effective removal of phosphate in the lake water, there were previous cases suggesting both increase (Shen et al. 2020) and decrease (Lukwambe et al. 2020, Li et al. 2010) of the measure. A possible explanation could be that as the bivalves are always going to produce feces, which would return a portion of phosphorus compounds into water, their net effect on phosphorus in water column remained dependent on factors like the bivalves' own population, presence of other organisms, water flow, and the sediment component (Jeppesen et.al 2012). Thus, further studies into the Asian clams' interaction with more kinds of phosphorus compounds may provide more solid understanding on the conditions under which they would be able to effectively control the amount of phosphorus in freshwater bodies. Despite the conflict of results from different studies on phosphorus compounds, it was widely accepted that controlling the phosphorus and nitrogenous compounds were able to effectively limit the nutrient supply to phytoplankton and thus constrain their growth (Shen et al. 2020, Sousa et al. 2009, Lukwambe et al. 2020). An efficient mitigation of excess nutrient would always be crucial in tackling freshwater eutrophication.

The significant decrease in nutrient concentrations and turbidity demonstrated an effective removal of eutrophication by Asian clams in both lakes' water. While the situation was controversial for dissolved oxygen, the overall study result can still reasonably support the conclusion that the Asian clams had performed an effective improvement of the water quality based on their high efficiency in reducing other parameters. Between the two types of water bodies, the Asian clams did not show differentiated performance as changes of the water parameters along the timeline did not convey inconsistency in the two water groups. The average final levels were also close between the water groups, indicating that the Asian clams were able to filter the available nutrient particles efficiently to these levels in the given time frame.

Analysis of the Asian clams' performance across Lake Anza water volumes

Result of experiment two was consistent with my expectation that there would a differentiated treatment effect among the water volumes. The stock of Asian clams was fully capable of remediating 20L water from Lake Anza. I observed a significant difference in mean percent changes for turbidity, nitrate, and ammonium, where the final levels of these parameters of the 20L group were lower than those of the 10L group and comparably close to their values of the 15L group. Only the percentage change of phosphate concentration did not show significant differences and the final values of all three volumes were the same. The 20L group had the highest level of DO at the end, while the 10L group experienced a clear DO drop to the lowest level among the volumes. These observations can all support that Asian clams still had high mitigation efficiency in the largest 20L water volume in this experiment, corresponding to a 5L to 6.7L per individual. Though the clams could release some of the nutrients they took in, the nutrients had not accumulated to a level to degrade water quality and enhance eutrophication in the 20L group (Lukwambe et al. 2020, Sousa et al. 2009). Therefore, the real threshold volume of Lake Anza water would probably be larger than 20L considerably.

Overall, responding to my general theme to explore the Asian clams' efficiency in freshwater eutrophication mitigation, this project was sufficient to demonstrate that filtration by the Asian clams can effectively remediate eutrophication. In the water environment set up in the experiment, the clams enhanced water clarity and decreased nutrient concentration in the water column significantly. For my question in their performance across water bodies, they answered with a stable treatment efficiency in water from both Lake Anza and Temescal. Regarding the last point I seek in this study: a threshold treatment volume of Lake Anza water, there wasn't a complete answer because the Asian clams' performance reflected that they were likely capable of remediating a remarkably larger water volume than the 20L in the experiment I conducted.

Limitations and future implications

Due to the accessibility of equipment and feasibility of environment set-up, there were some limitations on this study to increase the difficulty of obtaining a more comprehensive result. It was unfortunate that more accurate measurement methods for chlorophyll a and the nutrient concentrations were not approachable for the study. Advanced testing methods and equipment would provide stronger support to the evaluation of Asian clams' performance. In addition, obviously, lab scale experiment could not fully represent the natural water conditions and nutrient dynamics. The collected wet sediments can only partially represent the physio-chemical environment in benthic zone. Benthic plants would play an important role in nutrient cycle in natural water bodies (Shen et al. 2020). The microcosms setting cannot completely simulate the hydrodynamic either, which is another crucial perspective in interaction between filter feeders and algae (Vaughn and Hoellein 2018). Future studies should try to construct a water system that can better simulate the benthic conditions of the targeted lakes in order to make the result more applicable to the real eutrophic water bodies. Also, besides the more accurate measurement of chlorophyll a and the algae biomass, an analysis of the phytoplankton community of the water body throughout the experiment could help understand the selectivity in the bivalves' feeding and the algae's response to grazing (Mueller et al. 2004, Minaudo et al.

2021, Silva et al. 2020). These aspects would also be highly indicative knowledge when constructing a potential solution for eutrophication with the suitable bivalves.

A highly noteworthy point prior to application of the Asian clams for eutrophication mitigation is their invasive nature. Their wide invasion into Europe and the Americas had triggered severe negative impacts on local biodiversity and ecosystem functioning (Crespo et.al 2015). Degradation in the water environment and the investment for controlling the clams had also caused heavy economic loss in these regions (Rosa et al. 2011). Such invasive history of the Asian clams reflects that they should never be applied to natural water bodies currently without them. The regions of Asian clams' native origin (Asian) may have a better potential and lower risk for applying them for remediation use (Silva et al. 2020, Crepso et al. 2015). Still, deeper understanding of the clams' interaction with water ecosystem is necessary. Modeling on the relation between the Asian clams' abundance and environmental factors, as well as the manipulative studies over the ecological processes through which the Asian clams affect the ecosystem can both be useful for evaluating the suitability to apply them to a eutrophic water body (Sousa et al. 2018). In another perspective, the use of Asian clams in artificial and industrial water bodies may be more acceptable. There are studies investigating the application of Asian clams in industrial use for water cleaning. The bivalves' impacts on freshwater related industry were mild and it was possible to develop a positive economic model where the cost in dealing with biofouling by the clams could be offset by the profit from their treatment capacity (Domingues et al. 2020, Rosa et al. 2011). Heavy caution must be placed on the industrial water's connection and possible transportation to other water ecosystems to prevent undesirable invasion.

CONCLUSION

In this study, the Asian clams (*Corbicula fluminea*) had demonstrated outstanding filtering capability in water column and the associated efficient improvement in the water quality parameters related to eutrophication. They controlled the crucial nutrients for algae growth and enhanced water clarity. The clams maintained their high performance in both water bodies and across water volumes in the experiment. The volume of Lake Anza water that can be remediated by three to four individual clams was beyond the considered 20L volume in this study, further showing the strong mitigation capability of the clams. In terms their ability, Asian clams possess the potential to become a useful eutrophication remediator. However, as one of the most important invasive species, their ecological impacts must be more deeply understood prior to application. Construction of a practical proposal for eutrophication mitigation still require more comprehensive field studies on the Asian clams' interactions with biotic and abiotic factors within the freshwater ecosystem.

ACKNOWLEDGEMENTS

Enormous gratitude to my instructor Patina Mendez and graduate student instructor Jessie Moravek, who had been consistently providing significant support during the full academic year for this project. Patina Mendez connected me with relevant researchers and facilities for crucial resources, including but not limited to guidance on procedure design and access to experiment supplies. Her thoughtful advice was important in major modifications of this study. I would like to thank Jessie Moravek for her continual enthusiasm and valuable suggestions in every communication in the progress. Her robust support helped me overcome many obstacles in feasibility of conducting this study. Also, great thanks to Edward Culver and Hal MacLean of East Bay Regional Parks for the patient and crucial assistance during water collection from Lake Temescal and Lake Anza. Finally, my great gratitude goes to my peer Jieyuan Kan who had covered all the demand in transportation when searching for project supplies and gathering resources.

REFERENCES

Carpenter S.R., D. Ludwig, and W. A. Brock. 1999. Management of Eutrophication for Lakes Subject to Potentially Irreversible Change. Ecological Application 9: 751-771.

Crespo D., M. Dolbeth, S. Leston, R. Sousa, and M. A. Pardal. 2015. Distribution of Corbicula fluminea (Müller, 1774) in the invaded range: a geographic approach with notes on species traits variability. Biological Invasions 17: 2087-2101.

Domingues A., I. C. Rosa, J. P. Costa, T. A.P. Rocha-Santos, F. J.M. Gonçalves, R. Pereira, and J. L. Pereira. 2020. Potential of the bivalve Corbicula fluminea for the remediation of olive oil wastewaters. Journal of Cleaner Production 252.

Huang S., M. Wu, C. Zang, S. Du, J. Domagalski, M. Gajewska, F. Gao, C. Lin, Y. Guo, B. Liu, S. Wang, Y. Luo, A. Szymkiewicz, and R. Szymkiewicz. 2016. Dynamics of algae growth and nutrients in experimental enclosures culturing bighead carp and common carp: Phosphorus dynamics. International Journal of Sediment Research 31: 173-180.

Jeppesen E., M. Søndergaard, T. L. Lauridsen, T. A. Davidson, Z. Liu, N. Mazzeo, C. Trochine, K. Özkan, H. S. Jensen, D. Trolle, F. Starling, X. Lazzaro, L. S. Johansson, R. Bjerring, L. Liboriussen, S. E. Larsen, F. Landkildehus, S. Egemose, and M. Meerhoff. 2012. Chapter 6 - Biomanipulation as a Restoration Tool to Combat Eutrophication: Recent Advances and Future Challenges. Advances in Ecological Research 47: 411-488.

Li X., H. Song, W. Li, X. Lu, and O. Nishimura. 2010. An integrated ecological floating-bed employing plant, freshwater clam and biofilm carrier for purification of eutrophic water. Ecological Engineering 36.

Lin Q., Q. Chen, L. Peng, L. Xiao, L. Lei, and E. Jeppesen. 2020. Do bigheaded carp act as a phosphorus source for phytoplankton in (sub)tropical Chinese reservoirs? Water Research 180.

Lukwambe B., R. Nicholaus, W. Yang, and Z. Zheng. 2020. Blood clams (Tegillarca granosa) bioturbation alter succession of bacterioplankton community and nutrient removal performance in an aquaculture wastewater bioremediation system. Aquaculture 516.

Minaudo C., A. Abonyi, M. Leitão, A. M. Lançon, M. Floury, J. Descy, and F. Moatar. 2021. Long-term impacts of nutrient control, climate change, and invasive clams on phytoplankton and cyanobacteria biomass in a large temperate river. Science of The Total Environment 756.

Moustaka-Gouni M., and U. Sommer. 2020. Effects of Harmful Blooms of Large-Sized and Colonial Cyanobacteria on Aquatic Food Webs. Water 12:1587.

Mueller, C. R., E. G. Arnold, H. Turker, and D. E. Brune. 2004. Effect of silver carp (Hypophthalmichthys molitrix) and freshwater mussel (Elliptio complanata) filtration on the phytoplankton community of partitioned aquaculture system units. Journal of the World Aquaculture Society 35: 372-382.

Rosa I. C., J. L. Pereira, J. Gomes, P. M. Saraiva, F. Gonçalves, and R. Costa. 2011. The Asian clam Corbicula fluminea in the European freshwater-dependent industry: A latent threat or a friendly enemy? Ecological Economics 70: 1805-1813.

Shen, R., X. Gu, H. Chen, Z. Mao, Q. Zeng, and E. Jeppesen. 2020. Combining bivalve (Corbicula fluminea) and filter-feeding fish (Aristichthys nobilis) enhances the bioremediation effect of algae: An outdoor mesocosm study. Science of The Total Environment 727.

Silva, C., A. Anselmo, I. E. Macário, D. Figueiredo, F. M. Gonçalves, and J. L. Pereira. 2020. The bad against the villain: Suitability of Corbicula fluminea as a bioremediation agent towards cyanobacterial blooms. Ecological Engineering 152.

Sousa R., C. Antunes, and L. Guilhermino. 2008. Ecology of the invasive Asian clam Corbicula fluminea (Müller, 1774) in aquatic ecosystems: an overview. Ann. Limnol. - Int. J. Lim 44: 85-94.

Sousa, R., J. L. Gutiérrez, and D. C. Aldridge. 2009. Non-indigenous invasive bivalves as ecosystem engineers. Biological Invasions 11: 2367–2385.

Vaughn, C. C. and T. J. Hoellein. 2018. Bivalve impacts in freshwater and marine ecosystems. Annual Review of Ecology, Evolution, and Systematics 49: 183-208.

Wang, Y., X. Gu, Q. Zeng, Z. Mao, and W. Wang. 2016. Contrasting response of a plankton community to two filter-feeding fish and their feces: An in situ enclosure experiment. Aquaculture 465: 330-340.