Asian Clams *Corbicula flumina* contribution to algal growth in Lake Tahoe

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ABSTRACT

Over the past 80 years Asian Clams, *Corbicula flumina,* have extended their reach from Asia; spreading first to Oceania then across the Pacific to the Americas then recently to Lake Tahoe. During the summer of 2008 a filamentous algae was observed growing over many of the clam beds in Lake Tahoe. This study seeks to better understand how clam excrement affects the growth of algae; specifically do Asian Clams facilitate algal growth in Lake Tahoe? Three data sets helped explore this question: field chlorophyll, a lab experiment, and theoretical nutrients levels expelled by clams. Continuous chlorophyll measurements taken in the field showed the affect of a storm on the distribution of chlorophyll. To test the affect of clam excrement on algal growth we used three different concentrations, 0%, 2% and 50%, of clam excrement and a control. Carbon and Nitrogen, measures of biomass, were highest in the 50% treatment, lower in the 2% and 0% and at a constant minimum in the control, until the last day of the experiment. Results of the lab experiment were not significant because there were no replicates. Average clam densities and known clam excrement nutrient outputs suggest high theoretical levels of phosphorus and nitrogen in the water in close proximity to clam beds. The results of this study suggest that Asian Clams do facilitate the growth of algae; more growth in the lab with more clam excrement, and high theoretical levels of P and N that could support algal growth.

KEYWORDS

nutrients, oligotrophic, chlorophyll, Redfield ratio, clarity

INTRODUCTION

Invasive species disrupt food webs and alter nutrient flows of the native ecosystems they invade (Klerks et al. 1996; MaMahon 2002). In North American freshwater ecosystems, aquatic invasive species are one of the leading causes of high extinction rates of native aquatic fauna (Dextrase and Mandrak 2006). Some examples of this are the wide spread colonization of the Great Lakes and other inland lakes by Rainbow smelt and the quick spread of Zebra mussel in North American waterways. Both of these organisms have been instrumental in the extinction of one or more native species and are considered substantial threats to a number of endangered species (Dextrase and Mandrak 2006). Successful invasive species usually have r-selected life styles. In the case of invasive bivalve species this translates to high filtration and assimilation rates, and high fecundity (McMahon 2002). Asian clams have become a widespread successful invasive bivalve species in North America (McMahon 2002). Aside from competition concerns Asian clams affect ecosystems by altering nutrient cycles. Through the deposition of feces and psedufeces Asian clams release nitrogen and phosphorus to the substrate and waters that they invade (Klerks et al. 1996; Whittmann et al. 2009). It is for this reason that Asian Clams are considered a threat for the oligotrophic (nutrient poor) Lake Tahoe (Whittmann et al. 2009).

Lake Tahoe is a high altitude, freshwater lake, nestled in the Sierra Nevada Mountains between California and Nevada (Goldman 1988). Deep blue water and intense clarity are unique trademarks of Lake Tahoe. Over the past 70 years as anthropogenic activity increased on and around the lake, clarity has decreased from 70 m to about 30 m depth (State of the Lake 2009). Increased anthropogenic activity has caused a flux of nutrients and particulates to be released into the Lake. The flux of particulates and nutrients reduces clarity by increasing suspended sediment loads and fertilizing algae (Schuster and Grismer 2004). Many conservation efforts around the lake, such as storm water treatment, center on the idea of 'Keep Tahoe Blue'. One of the reasons why Lake Tahoe is blue is because algal growth is limited by very low nitrogen and phosphorus concentrations in the water (Goldman 1988). One of the most recent threats to Lake Tahoe's clarity is the recent invasion of the freshwater bivalve Asian clam, *Corbicula fluminea,* because of their potential to add limiting nutrients to the water (Whittmann et al. 2009).

Over the past 80 years Asian clams have extended their reach from Asia; spreading first to Oceania then across the Pacific to the Americas (Sousa 2008). After a history of invasion in North America, Asian clams successfully established in Lake Tahoe. Large beds of Asian clams

were first found in Lake Tahoe in 2008 (Whittmann et al. 2009). The invasion is focused on the southeastern shore of Lake Tahoe (figure 1), where large area, high-density, beds of clams are found in 3-5m of water (Whittmann et al. 2009). The potential impacts that Asian clam could have on Lake Tahoe include, outcompeting other benthic organisms, decline of plankton communities through high filtration rates, declining the aesthetics of recreational beaches when dead clams and algae wash ashore, and degradation of water clarity (Whittmann et al. 2009). Some of these impacts have occurred; clam matter has been washed up on some of the southeastern beaches of Lake Tahoe, and water clarity has been impacted with an increase in algal growth near the clam beds.
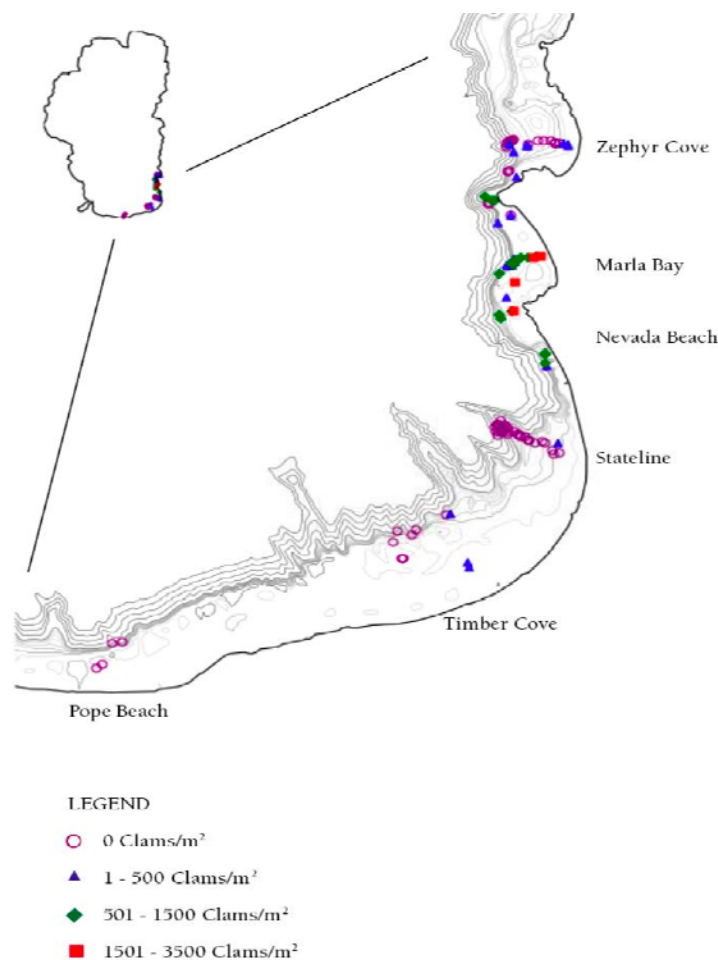

Figure 1. Occurrence, distribution and densities of Asian Clams in Lake Tahoe.

During the summer of 2008 a filamentous algae, primarily *Zygnema sp.*, was observed growing over many of the clam beds in Lake Tahoe (Whittmann et al. 2009). The unattached *Zygnema sp.* floats above the clam beds during warmer summer months and dies as the waters

cool during the fall (Whittmann et al. 2009). Algal growth in many lakes shows temporal growth with highest production rates in the warmer summer months and lower production in the winter months (Nozaki et al. 2003; State of the Lake 2009). The occurrence of algae in close proximity to Asian clam beds in Lake Tahoe shows a seasonal pattern, however because the algal growth is localized perhaps there is a localized source of nutrients (Whittmann et al. 2009).

This study seeks to answer the question; do Asian Clams facilitate algal growth in Lake Tahoe? In order to answer this question I first looked at a record of chlorophyll a in the field to characterize the presence of algae next to the beds of clams. Then, I conducted a lab experiment with algae and clam excrement to assess the affect of clam excrement on algal growth. Last, I used field data to calculate the theoretical nutrients available in the water to see if the output was high enough to theoretically support an algal bloom. The very localized nature of the algal blooms and the fact that Asian clams add key fertilizing nutrients back to the water leads me to believe that Asian clams are the cause of the localized algal growth, and thus should be considered a threat to the clarity of Lake Tahoe.

METHODS

Study site

Lake Tahoe has a maximum depth of 505m and average depth of 313m. The lake contains 156 km^3 of water, which has a residence time of about 700 years. The surrounding watershed is about 800 km^2 and contains a number of small streams that drain into the lake (Goldman 1988). Our field study site was on the southeast side of Lake Tahoe in Marla Bay (Fig. 1). The Asian clams inhabit the sandy substrate a small distance from the shore, in about 3-5m of water.

Field chlorophyll

To better understand the growth and presence of algae in the field I analyzed a data set of field fluorescence (ppb) from Tahoe Environmental Research Center (Whittmann, unpublished data). A fluorescence probe recorded fluorescence, a measure of chlorophyll a, every half hour for one month. Chlorophyll a can be used as a relative measure for biomass. Running averages of four half hours were used to smooth the data; six days of the smoothed data were plotted on the same graph to look for a diurnal pattern in the chlorophyll. To look for some of the larger

trends, the data set was then smoothed by taking six-hour averages. In the middle of May there was an abrupt change in chlorophyll; a t-test was run to see if the change was significant.

Lab experiment

An experiment was conducted in lab at the Tahoe Environmental Research Center (TERC) in late June 2009 to understand how clam excrement affects the growth of algae. We decided that a sterile lab setting would be the best way to eliminate many confounding variables, such as temperature, weather, light, and depth. The objective was to test the effect of Asian Clams on algal growth in Lake Tahoe so we used field algae and field clams for the experiment. We waited for algae to bloom in the field; it was primarily filamentous, unattached *Zygnema sp.* The field alga was grown with excrement from the invasive Asian clams.

This experiment needed three ingredients, clam juice (excrement), algae, and growth medium. Clam juice (excrement) was prepared by scrubbing ten medium Asian Clams from the field, putting them in 200 ml of deionized water and letting them evacuate their systems for 12 hours. Particulate matter was then removed from the system by filtration through a GF/C filter. The algae was prepared by homogenizing the field sample with a hand blender, filtering the field sample to eliminate the water, then measuring out 2 mg of algae on a scale. The growth medium was prepared to standards, in lab.

To test the effect of clam juice on algal growth we used three different concentrations of clam juice and a control. The three percentages, 0%, 2% and 50%, were chosen because we wanted to test a high concentration and a low concentration, they were also convenient to measure. These percentages are out of the total 50ml of liquid in all of the treatments.

To measure algal growth over time we found it necessary to make multiple flasks of each of the treatments (see Table 1) for a total of 32 flasks, so that we could filter an entire flask, for carbon and fluorescence, on each of the measurement days. Any single flask contained 50 ml of fluid: 25 ml of growth medium, 0 ml, 1 ml or 25 ml of clam juice depending on the treatment; deionized water was added until each flask contained 50 ml of solution. The control was a check for contamination, which contained just growth medium and deionized water; if algae grew in any of the controls we knew that there had been contamination between flasks. Each of the treatments was inoculated with 2 mg of the filtered field algae. All 32 of the flasks were then placed in the variable temperature room, which was set at 18 C, on a shaker table under

florescent lights. 18 C reflects midsummer water temperatures of Lake Tahoe where algae grow well.

We ran the experiment for a period of ten days. We found that the most accurate way to measure algal growth was to filter an entire flask for carbon and one flask for fluorescence (see Table 1). Thus on each measurement day we were eliminating two flasks from each treatment. Carbon analysis can be extrapolated to biomass. Fluorescence is a measure of chlorophyll, which can also be extrapolated to biomass. We were interested in how the algae grew with time, thus we wanted to collect data for more than just the starting and ending days. Carbon and fluorescence measurements were taken on days 1, 3, 7, and 10 of the experiment (Table 1).

Table 1. Layout of flasks and reading days. On each reading day 8 flasks will be taken out of the experiment and filtered. This will monitor the growth of the algae through the experiment. The boxes labeled (C) represent the flasks used to measure Carbon; the boxes labeled {F} represent the flasks used to measure fluorescence.

Day	Control		0%		2%		50%	
1	(C)	{F}	(C)	{F}	(C)	{F}	(C)	{F}
3	(C)	{F}	(C)	{F}	(C)	{F}	(C)	{F}
7	(C)	{F}	(C)	{F}	(C)	{F}	(C)	{F}
10	(C)	{F}	(C)	{F}	(C)	{F}	(C)	{F}

All of the carbon filters were dried, packaged and sent to the UC Davis ANR Analytical Lab for analysis. Fluorescence filters were wrapped in foil and placed in the freezer to await analysis at TERC. The fluorescence filters were never analyzed and thus are not discussed in the following sections.

For analysis I will be comparing the carbon nitrogen ratios for each of the different treatments. This will provide insight into how the alga is growing; a shift in the C:N ratio from the 0% clam excrement treatment may indicate that the alga has the nutrients to grow at a more optimal rate.

Theoretical abundance of N and P

To test the if the density of Asian clams found in Lake Tahoe could produce enough nutrients to support an algal bloom, I used clam density measurements, with experimentally found phosphorus and nitrogen excretion rates for Asian clam to calculate expected nutrient loads of the water. The calculation I used was: average density x average nutrient output per clam = theoretical nutrient load. This will be compared to the theoretical nutrient levels that algae needs and the background nutrient levels of Lake Tahoe.

RESULTS

Field chlorophyll

The smoothed chlorophyll data shows no discernable trend over the course of a day (Fig. 2). Individual lines show peaks but when multiple days are overlain no unifying trend appears.
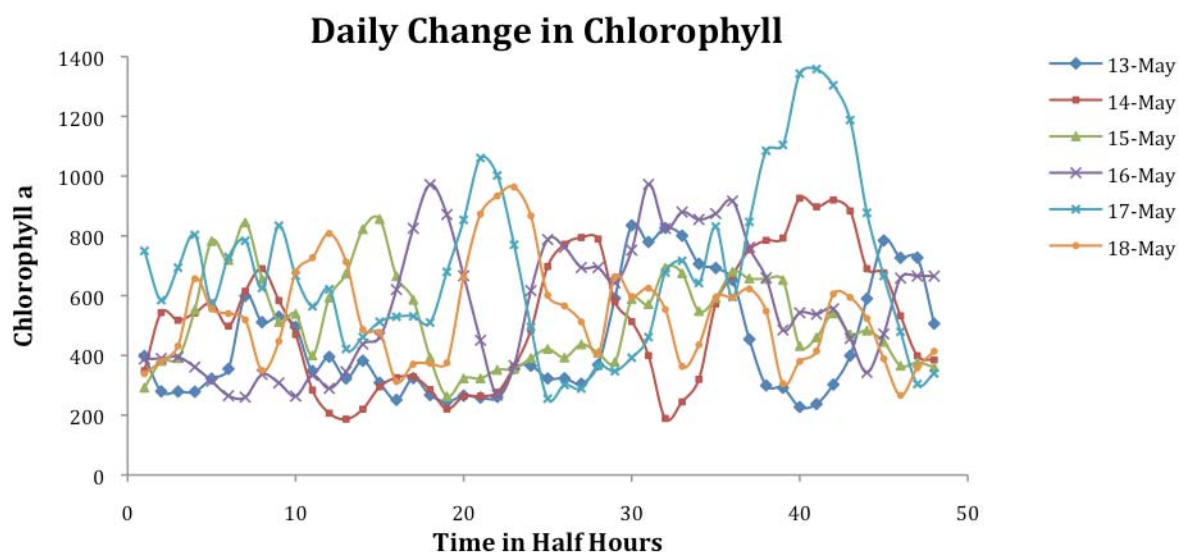

Figure 2. Smoothed chlorophyll data fluxes over a twenty-four hour period. Each point is a running average of four points, itself plus the three next points. Time is shown in half hour time steps; chlorophyll is unitless.

The six-hour averaged data shows large fluxes of chlorophyll in the beginning of May until the storm event, at which point the chlorophyll in the water drops and goes through smaller fluxes (Fig. 3). Around May 19th the recorded chlorophyll drops. A t-test shows that Chlorophyll noon readings after May 19th are significantly lower (p=0.002, n=10) than before May 19th.
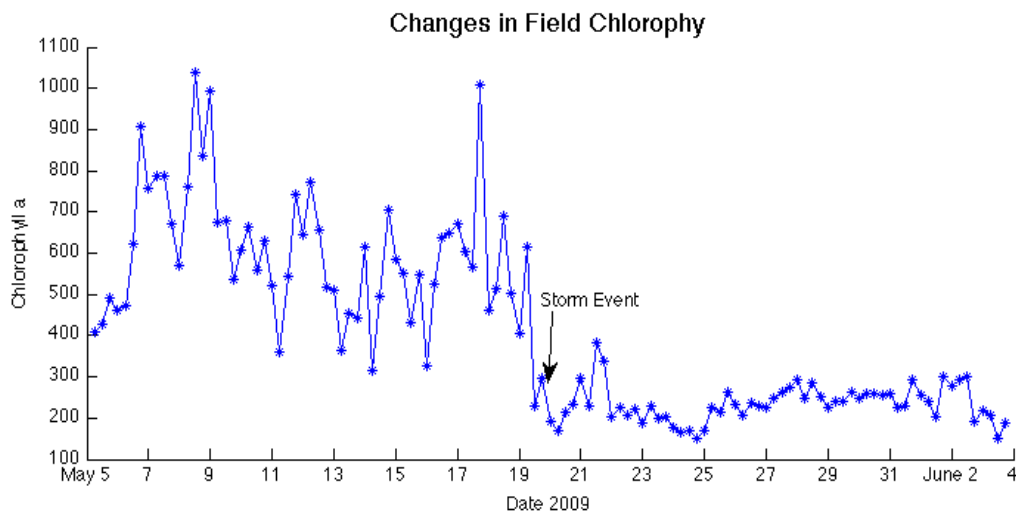
Figure 3. This graph shows the daily fluxes of chlorophyll in Marla Bay, Lake Tahoe. Each point on the graph is a six hour average; starting with May 5, 2009 from 12am-6am. The measurement of chlorophyll is unitless.

Lab experiment

The lab results reflected roughly what we expected until the last day of the experiment; C and N were highest in the 50% treatment, lower in the 2% and 0% and at a constant minimum in the control (Fig. 4). The last measurement day the 50% treatment had the lowest C and N values and the 0% treatment had the highest C and N values.
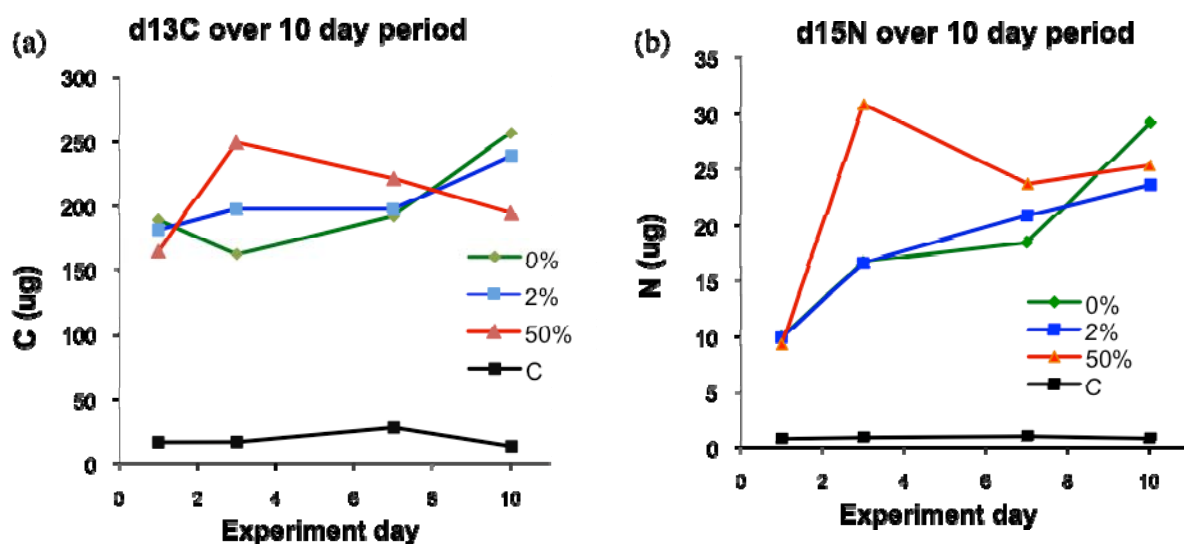

Figure 4. Amount of (a) C and (b) N over the ten-day Asian clam/Zygnema growth experiment for the three different treatments and the control. Lines are drawn through the marks to illuminate the trends, however it is important to note that the data is not continuous.

The C:N ratios for the lab experiment show almost no variation between the treatments (Fig.3). All of the treatments have higher C:N ratios than the Redfield C:N ratio (~6.6), which is the ratio that photosynthetic organisms would use carbon and nitrogen if both were readily available. The control has a much higher ratio then the treatments; the 50% treatment has a slightly lower ratio, but shows no larger variation then is seen on the first day where all the treatments should be similar.
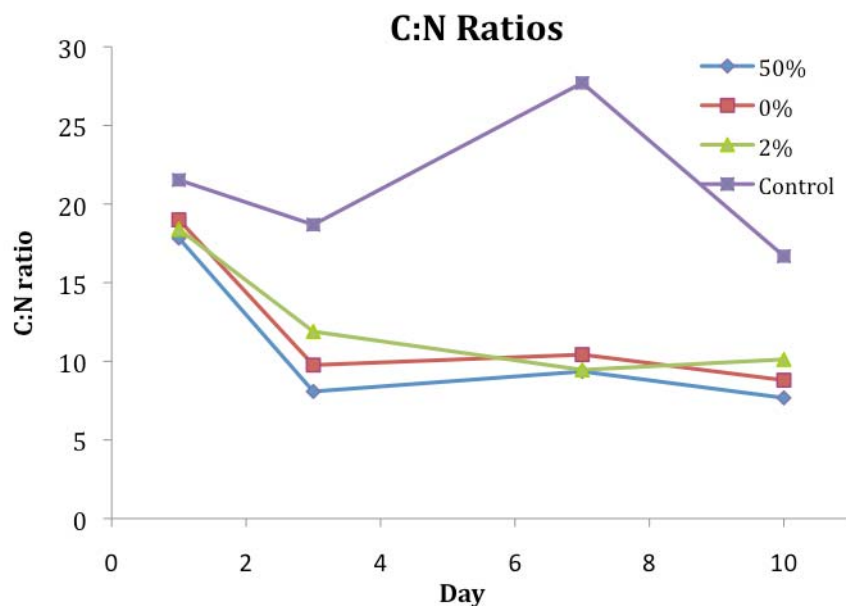

Figure 5. C:N ratio for the three treatments and the control over the ten-day experiment.

Theoretical abundance of N and P

Average clam densities and known clam nutrient outputs give rise to high theoretical levels of phosphorus and nitrogen proximate water to clam beds (Table 2).

Table 2. Theoretical estimates of total P and N nutrients excreted by average measured densities of Asian Clams in Marla Bay, Lake Tahoe.

Average Clam Density in Marla Bay	$2000/m^2$
Average NH_4 (ppb/clam/day)	89.9
Average SRP (ppb/clam/day)	12.35
Total NH_4 (m^{-2})	179800 ppb/day
Total SRP (m^{-2})	24700 ppb/day
Ratio N:P	7.28

DISCUSSION

This study sought to better understand how Asian clams affect the growth of algae in Lake Tahoe. Understanding this connection is especially important with regard to Lake Tahoe, which is known for its transparent, low nutrient waters. Asian clams threaten the clarity of Lake Tahoe by releasing nutrients, through their excrement, to the immediate water column. The results of this study suggest that Asian clams facilitate algal growth by supplying algae with essential nutrients that are typically low in Lake Tahoe.

Field chlorophyll

The flux of chlorophyll from field measurements did not show a discernable diurnal pattern (Fig. 2). This is contrary to trends found in other studies, where max chlorophyll was observed in the afternoon and minimums at night (Doty and Oguri 1957; Happy-Wood 1993). Diurnal fluxes in chlorophyll correlate directly to the primary production in the water (Happy-Wood 1993). Production is highest when solar radiation is at its peak, and lowest during the night when there is no radiation (Doty and Oguri 1957). I believe the lack of discernable pattern in the chlorophyll data is a result of measurement method and noisy data and not a true attribute of algae in Lake Tahoe.

Asian clams' feeding cycle closely matches the diurnal cycle of chlorophyll production found in other studies. Asian clams filter feed during the during the day, with maximum metabolism in the middle of the day, then they close at night and drop their metabolism drops (Ortmann and Grieshaber 2003). Ortmann and Grieshaber (2003) hypothesize that the Asian clams metabolic cycle follows the availability of food. Following this hypothesis, the metabolic cycle of Asian clams is driven by the diurnal cycle of chlorophyll. As Asian clams feed they excrete nutrients, which then drive primary production.

Chlorophyll levels significantly decrease around May 19th after a large storm (Fig. 3). Other studies have found that increased mixing causes increased algal growth because richer nutrient waters from the bottom of the water column are mixed to the surface where nutrients are depleted which causes and algal bloom (Vincent 1983). Increasing nutrients in the water is strongly correlated to an increase in algal biomass (Biggs 2000). Increased productivity after the storm was probably not observed at the field site because the alga was being fertilized by the nutrients from beds of Asian clams. When the storm mixed the lake waters it dispersed the algae, and replaced the nutrient rich water next to the clam beds with nutrient poor water from

the rest of the lake, which is why we see a drop in chlorophyll around May 19th. If measurements continued, we would probably observe a steady increase in chlorophyll as the alga reestablished and nutrients accumulated in the water. From these results we are reminded that it is important to recognize that Marla Bay interacts and is influenced by the rest of the lake and that the presence of alga due to nutrients excreted by Asian clams is a localized phenomena.

Lab experiment

The results of the lab experiment suggest that Asian clam excrement does contribute to algal growth (Fig. 4). C and N relate to biomass, thus the more C and N the larger the biomass of the sample. C and N measurements for the first day should be similar because the algae was given no time to grow in solution before it was filtered for the sample. Measurements on days 3 and 7 showed that the alga was growing more with more clam excrement because the algae was less limited by essential nutrients in the presence of the clam excrement (Biggs 2000). On day 10 of the experiment, the opposite became true, the 0% treatment had the highest biomass and the 50% treatment had the lowest. This may have occurred because the alga in the higher concentrations was able to grow fast at first and use all of its nutrients, but began to die when the nutrients had been used (Diersing 2009). Further death may have occurred as the dying algae decomposed and reduced the dissolved oxygen in the water, which would limit the growth of the remaining algae (Diersing 2009). The treatment without clam excrement was limited by an essential nutrient, probably P or N, and thus grew at a slower rate but grew for a long period of time. If our results are accurate, I would not expect to see the same decrease in algae in the field as in the lab because clams would continually replenish nutrients through excretion.

C:N ratios show very little variation between the three treatments (Fig. 5), however, even a slight difference in the ratio may signify a shift in algal growth rate (Geider and La Roche 2002). The variations between the different treatments reflect what I would expect to see; the higher the concentration clam juice treatments have lowers C:N ratios. Photosynthetic organisms will often use C and N in a 6.6:1 (Redfield ratio) ratio if the nutrients are available. A larger ratio means that N is a limited nutrient (Christian 2005). A shift in the C:N ratio may have a significant affect on algal growth, Goldman et al. (1979) found that a shift in the C:N ratio from 7.1 to 20 resulted in 80% less productivity in the phytoplankton *Dunaliella tertiolecta*. This leads to three possible interpretations of the experimental data. First, the 50% treatment was less limited because it had more nutrients so the algae grew at a ratio close to the Redfield

ratio, followed by the 2% at a slightly higher ratio then the 0% at a ratio above that. Second, the variation seen in the treatments is independent of the clam excrement and reflects some natural kind of algal growth variation (Geider and La Roche 2002). Finally, algal growth is limited by a nutrient other than nitrogen (Chang et al. 1992).

Theoretical abundance of N and P

Theoretically, this simple model of nutrients produced by Asian clams suggests that there are sufficient amounts of phosphorus and nitrogen added back to the water to promote an algae bloom.   The average N:P ratio in Lake Tahoe is 54; much higher the 16 of the Redfield ratio. Thus growth of algae in Lake Tahoe is primarily limited by phosphorus (Chang et al. 1992). Calculations show that Asian clam's excrete N and P in a lower ratio than the Redfield ratio, so there is relatively more phosphorus being excreted. The estimated ratio of 7.28 is probably low compared to what the ratio is in actuality, highly eutrophic waters may have N:P ratios around 9 (Geider and La Roche 2002). These theoretical levels of N and P derived from experimental results, suggest that beds of Asian clams could excrete enough nutrients to support a local algae bloom (Geider and La Roche 2002).

Limitations

The first limitation I faced was trying to find a signal in the field chlorophyll data. Measurements were taken every half hour, but the difference between one measurement and the next could be as much as 1200. I think that it is unlikely that chlorophyll would increase so much in a half hour then decrease that much in the next time step. I think this is due to the sensitivity of the fluorescence probe; perhaps it would measure high chlorophyll if there was a piece of algae in the beam and then lower if it was just phytoplankton. I think that the noise in the data drowned out any daily pattern that may have been present in the field, but the noise was not high enough to drown out the significant drop in chlorophyll.

The biggest limitation of this project was not having replicates for the lab experiment. We spent the first part of the summer running a number of pilot studies by the time we started the experiment we were short on time, so the experiment could not be run again. Thus the results and variations in the data set were not as meaningful or significant as I would have hoped because the experiment was run without replicates. This means that the differences in C and N may be due to natural variations in algae growth and not be dependent upon the clam excrement

at all. In order to decisively state that Asian clams promote algae growth, the experiment needs to be run again with replicates.

The theoretical nutrient estimates were limited by the complexity of nutrient cycling. The simple calculations used did not take into account any other organisms or processes that would deplete nitrogen and phosphorus thus the calculated nutrient levels are higher than I would expect to find in actual measurements.

Future Directions

Future studies that examine the connection between algal growth and Asian clams would rerun the lab experiment with replicates so significance of different growth rates could be determined. Other studies would also examine the connection between degree of eutrophication of a lake and Asian clams affect on water clarity. Some studies have found that the presence of Asian clams clears the water because of their high filtration rate (Hakenkamp and Palmer 1999). However this study suggests that Asian clams would facilitate the decline of water clarity. It would be interesting to see how eutrophic a lake would have to be for the Asian clams to make a noticeable difference in water clarity.

Summary

Our results suggest that Asian clams do facilitate the growth of algae in Lake Tahoe. For most of the lab experiment the treatment with the most clam excrement grew the most. The theoretical levels of P and N that could be produced by a bed of clams are sufficiently large enough to supply the phosphorous limited water with enough nutrients to promote algae growth. The field chlorophyll data shows that the algae is susceptible to storm events, a local penomena, and takes some time to reestablish. These combined results give us a little more insight on how Asian clams are affecting Lake Tahoe. While our results suggest that Asian clams facilitate the growth of algae locally, I do not believe that the presence of Asian clams in Lake Tahoe will significantly decrease the overall clarity. Lake Tahoe is too large for all of its water to become less transparent from the presence of Asian clams on its southeastern shore. However, if Asian clams are permitted to spread the effect of increased algae could be felt along the sandy beaches of the south and eastern shores of Lake Tahoe.

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