Density of Quagga and Zebra Mussels at Different Depths in Torch Lake, 2023

Authors:
Isabelle Borden[1], Carter Massey[2], Josh Woollard,[3] Jeanie Williams[4]

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Interns:
Isabelle Borden[1], Carter Massey[2], Josh Woollard[3]

Advisors:
Jeanie Williams[4], Gary Bart[5], Alyssa Cogan[6], Beth LaVasseur[7]

[1] Kalkaska High School
[2] Bellaire High School
[3] Central Lake High School
[4] Wayfinder Facilitation
[5] Three Lakes Association
[6] Michigan State University (undergraduate)
[7] Volunteer

Introduction

Quagga mussels (*Dreissena bugensis*) and zebra mussels (*Dreissena polymorpha*) are invasive species that have caused great ecological change in the Great Lakes and in the hundreds of freshwater lakes and streams they have invaded across the United States and Canada (Madenjian et al, 2015).

Zebra mussels have been known residents of Torch Lake for some time (Platte et al, 2007), but quagga mussels were presumed absent until recently.

Figure 1: Quagga mussel (left) and Zebra mussel (right)

There have been numerous studies on quagga and zebra mussels over the years. Tip of the Mitt Watershed Council looked for quagga mussels throughout Torch Lake in 2015, however they only sampled really deep (120, 200, & 280 feet) and really shallow (2-20 feet) but not in between (Tip of the Mitt Watershed Council, 2015). Since we know quagga mussels are non-existent or rare in these locations, this was a significant limitation of their study.

The Michigan Department of Environment, Great Lakes, and Energy also did a survey in 2015, looking for invasive species in different parts of Torch Lake, and unlike the Tip of the Mitt Study, quagga mussels were found (EGLE, 2015). The DNR survey intended to determine general abundance of each target species, so although it firmly established the presence of quagga mussels for the first time, it did not provide much information about density or distribution of quagga mussels throughout the lake.

Georeferenced aerial photography collected by Art Hoadly of Three Lakes Association has also been a good source of information to track different changes in the water and establish a historical record. Unfortunately aerial photography can't give us direct information on mussels in Torch Lake.

Previous TLA internships have also provided a lot of information on quagga mussels in Torch Lake. Last year (2022) TLA interns were not focused on quagga and zebra mussels but other bottom-dwelling species, yet, they found an abundance of quagga mussels where they sampled (Brown et al, 2022). Their sampling gave us a good sense of how abundant the mussels might be throughout Torch Lake. The next most recent sampling of the bottom of Torch Lake was 2007 also by TLA interns. Then, no quagga mussels were found and zebra mussels were found in only 16% of samples (Platte et al, 2007). Clearly a lot has changed in 15 years.

Finally, over the winter (2022-23), mounds of quagga mussel shells were found washed up on the shoreline for the first time, as a clear indication that quagga mussels were now abundant in Torch Lake (Figure 2). This observation made our study on quagga and zebra mussel densities in Torch Lake all the more urgent.

Figure 2: Mussel shells washed up on Torch Lake shoreline winter 2022-3

Quagga and zebra mussels were first found in Lake Michigan in the early 1990s. Since then, the ecology of Lake Michigan has experienced a total rearrangement, in large part due to the filtering capacity of *Dreissenid* mussels (Madenjian et al, 2015). They remove the energy and nutrients from the water column – mostly in the form of microscopic plant and animal life – and transfer them to the bottom of the lake in the bodies of the mussels and in the form of feces and pseudofeces produced by the mussels. This moves the main pool of energy and nutrients from the water column to the bottom of the lake, and makes it available in a very different form. A concentration of nutrients on the lake bottom feeds the algae and plant life that now have even more access to sunlight (water gets more transparent as mussels filter out particulate matter and microscopic life from the water column) as well as numerous other bottom-feeding species. All of this can also have catastrophic effects on certain invertebrates and fish (Madenjian et al, 2015).

A 30-year study done in Lake Michigan on benthic species, including quagga and zebra mussels, showed how the quagga mussel population grew to dominate nearly all parts of the lake, while the zebra mussels population grew some and then shrank to vanishingly small numbers (Figure 8; Nalepa et al., 2014; Mehler et al., 2020).

Lake Michigan is similar to Torch Lake in many ways. Torch Lake is a very large, very deep inland lake, reaching 302 feet deep (Tip of the Mitt Watershed Council, 2023). It also has very clear water, very low levels of nutrients, and high calcium carbonate content (GLEC, 2006). These features make it something of a microcosm of Lake Michigan, which is also deep, low in nutrients, and high in calcium carbonate.

The lakes are also geographically very close to each other (0.5 miles at the closest point), and hydrologically connected (11 miles of waterways between them). Because of all of this, Lake Michigan might be able to act as a bellwether for Torch Lake. The species that take up residence in Lake Michigan are likely to respond in a similar way when they encounter Torch

Lake. Furthermore, any species that invades Lake Michigan is likely to make its way to Torch Lake eventually.

Much of the economy surrounding Torch Lake is dependent on lake-based tourism and high property values on sought-after lake-fronts. This means that changes to the lake, due to invasive species or other ecological factors, could have a meaningful impact on the region’s continual thriving. Additionally, invasive mussels could result in losses of some native species or change the character of the lake altogether. This would mean that future generations would not have access to what was once available to their parents and grandparents.

We are already seeing undesirable ecological change in Torch Lake in the form of large patches of bottom-based algae called golden brown algae (GBA). This algal complex is composed of native species, but they are growing in disproportionate numbers, and causing the sand to change from a nice pale color into an unsightly golden brown, potentially deterring tourists from our beautiful lakes, as well as making our lakes less beautiful.

Because invasive mussels have the potential to change the location and abundance of nutrients in a lake, there could be a connection between invasive mussels and the presence of GBA. This study will not attempt to link these two phenomena, but the results of this study will let us know if the densities of mussels in Torch Lake are high enough to invest in determining the nature and magnitude of the linkage, if any. All of this means this study should be of great interest to the community.

In addition to determining if the density of mussels might be high enough to influence nutrient availability in Torch Lake and therefore support the presence of GBA, this study also had some very basic goals.

First, we wanted to determine the depths at which quagga mussels and zebra mussels are most common in Torch Lake. This will help us understand which parts of the lake are most favorable to quagga and zebra mussels and will help us describe the nature of these two populations. We expected quagga mussels to be quite common around 80 feet, because the 2022 TLA interns found quite high numbers in that range (Brown et al, 2022). Based on this same data set, we also expected to find them as shallow at 40 feet and as deep as 200 feet. What we didn’t know was if this pattern would be consistent throughout the lake, or if systematic sampling would reveal any new patterns.

We also wanted to determine mussel density at all of the collected depths. Density allows us to compare our results with other studies and track changes over time. Knowing density can also help us understand how severe the infestation is, and estimate the total number of mussels in Torch Lake and the filtering capacity of the population. This study will not give us definitive information about the impact the mussels are having on the lake, but it will let us know if further study is warranted.

To answer these questions, we determined quagga mussel density at five different depths and in five locations around Torch Lake. We also measured the length of all of the mussels we collected. A systematic study like this has not been done before in Torch Lake.

Methods

Torch Lake is part of the Elk River Chain of Lakes Watershed in Antrim County in Northern Michigan. The lake has 41 miles of shoreline and at its deepest point is 302 ft deep (Tip of the Mitt Watershed Council). The lake gradually deepens to about 50 feet where it then plunges quickly to approximately 95 feet. Beyond this depth, the lake has shallow slopes. The primary outflow is Torch River, and the major inlet is Clam River.

In our study, we used a Petite Ponar dredge, an object designed to bring mud and objects from a lakebed by scooping up sediment. It has a sample area of 6”X6” (152 mm X 152mm) (Pine Environmental).

When collecting Ponar samples at 125 feet or less, we took videos of the lakebed using a GoPro Hero 3. We used this depth because the GoPro was waterproof to 144 feet. Video footage allowed us to see mussel distribution and density. We did not analyze the video for mussel density, but we looked at it to see the effectiveness of our Ponar deployment, and to get a sense of how representative our samples were of the lakebed.

In addition to Ponar drops, we also took two video transects of the lake bottom with the GoPro Hero 3. We wanted to see how the mussels were distributed over larger areas instead of just seeing them at certain small areas and depths. We secured the GoPro to a rope with a weight, dropped it in the lake, and dragged it behind us from a boat. As the boat moved, we took in or gave out rope so the GoPro was pulled across the lakebed. This footage has been archived for future examination.

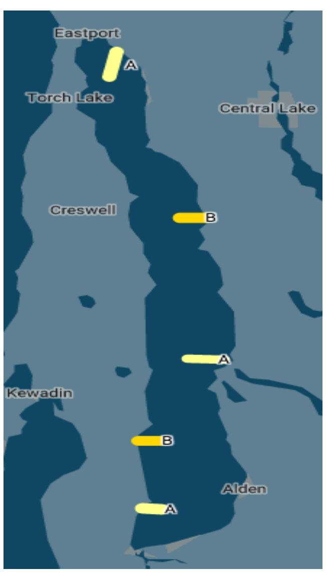

Figure 3: Map of Transects used in this study. In clockwise order from the top, North transect (A), East Side transect (B), Clam River transect (A), Deep Water Point transect (A), and French Point transect (B).

We collected samples along 5 transects (Figure 3). In all transects, we took two samples at depths of 10, 30, 75, 125 and 175 feet. The 10 foot depth was chosen because it is the deeper part of where GBA is seen. The 75 foot depth was chosen because it is in the middle of a steep dropoff, and last year's interns found mussels there (Brown et al, 2022). The 30 foot depth was chosen because it was about halfway between the 10 and 75 foot depths. The 125 foot depth was chosen because it was after the dropoff. The 175 foot depth was chosen because it was in the profundal zone. At the 175 foot East Side drop, we were only able to take one sample.

In addition to these depths, we took extra samples at the 90 and 50 feet depths at two transects. We did this to get more refinement on when the increase in mussels occurred before or after 75 feet. Because of the lakebed dropoff, we found that both depths were too close to 75 feet so it was difficult to sample from these locations, and it took more time than we really had to continue sampling at extra depths. We also took three exploratory samples from 275 feet along the middle of the lake. We sampled at this depth because it had not been sampled before and we wanted to see what the mussel sizes and distribution looked like at that depth.

When the Ponar sample was hauled up, we emptied the sample in a bin, photographed it, mixed the sample with some water, and poured the mixture through a sieve (opening size 0.057 inches or 36.8 mm), and collected the drain water in a different bin. The sieve filtered out the sediment, leaving us with mussels. We added more water to ensure that the majority of the sample was rinsed. Then, we photographed the contents of the sieve. We collected live mussels in plastic jars labeled with the sample number to measure later, and the drain water was poured in the lake. The bins, Ponar, and sieve were rinsed. After counting, the mussels were preserved in alcohol.

Furthermore, we recorded the presence of other species that were in the sample. In many of the samples, there were midge larvae and scuds, and once, we found a small crayfish. No counts were made of any of these species.

We also observed substrate color and type. The color categories we used were black, dark gray, medium gray, light gray, dark brown, medium brown, tan/light brown, and olive brown. The substrate types were mud, sand, or rock.

The mussels were identified as zebra or quagga mussels, and measured using calipers. The mussels' lengths were recorded in groups of 5mm: <5 mm, 5 to <10mm, 10 to <15mm, etc. We did not record the mussels' actual length to save time, but the mussels were preserved in alcohol to enable future analysis.

We collected samples on June 16, 22, and 29, and July 13, 20, and 27, 2023.

To analyze our results we decided to use median instead of mean because median can be a better description of the data than mean when there are outliers in the data. We had an outlier in one of our samples at Deepwater Point (Figure 7). Table 1 shows how median compared to mean for mussel density at different depths.

We also calculated, very roughly and as conservatively as we could, the number of quagga mussels in Torch Lake. A mature mussel will filter approximately 1 liter of water per day, and we estimate that 60% of the quagga mussels we collected are mature. This is because 58% of quaggas were over 10mm, and since quaggas are mature in sizes smaller than this, it felt safe to round up a bit for ease of calculation.

We used surface area to calculate the area of the lake, even though the actual surface area of the bottom is much larger. We made the calculation with median density rather than mean density, since higher density areas were concentrated in a relatively small area. This is the calculation we used:

Number of mussels = median mussel density x lake surface area
Number of days to filter all of Torch Lake = number of mussels x 0.6 x volume of water filtered/mussel/day x volume of water in Torch Lake

Surface area of Torch Lake came from Tip of the Mitt Watershed Council, 18,473 acres. Volume is agreed upon by many sources, 0.78 cubic miles.

Results

We collected 1,546 mussels from 5 transects, 27 individual locations, and 53 individual samples, from 8 foot water to 177 foot water. We also collected 26 mussels from the deepest areas in the lake at three locations. We found vastly more quagga mussels than zebra mussels in Torch Lake. Almost 94% of mussels we collected were quagga mussels (Figure 4).

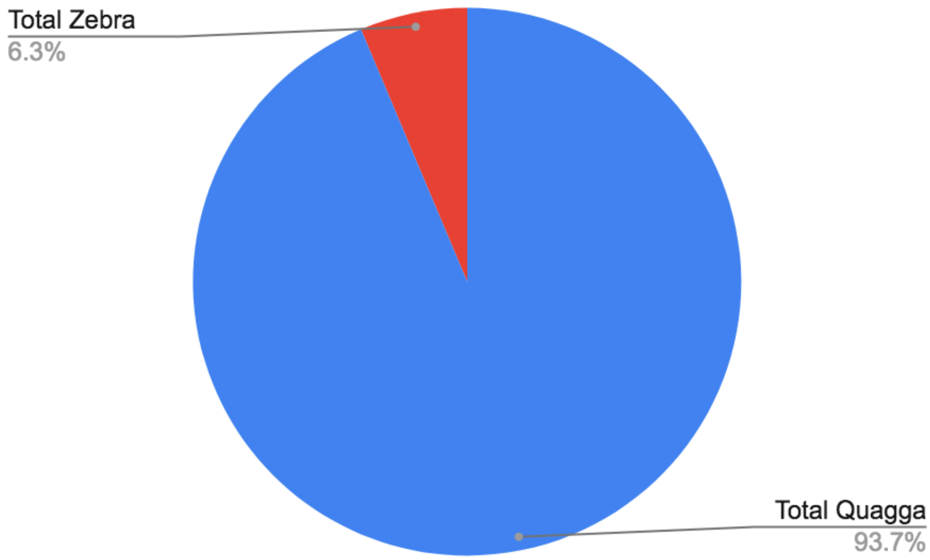

Figure 4: Percentage of all collected mussels (below 180 feet) that were quagga and zebra mussels

Quaggas were found at every depth we took samples from, except for the 10 foot depth category. In contrast, zebra mussels were mostly limited to the shallower depths (Figure 5). Figure 5 displays the median of our data set, so although it suggests that there were no zebras found over 75 feet, we did find one or two from time to time.

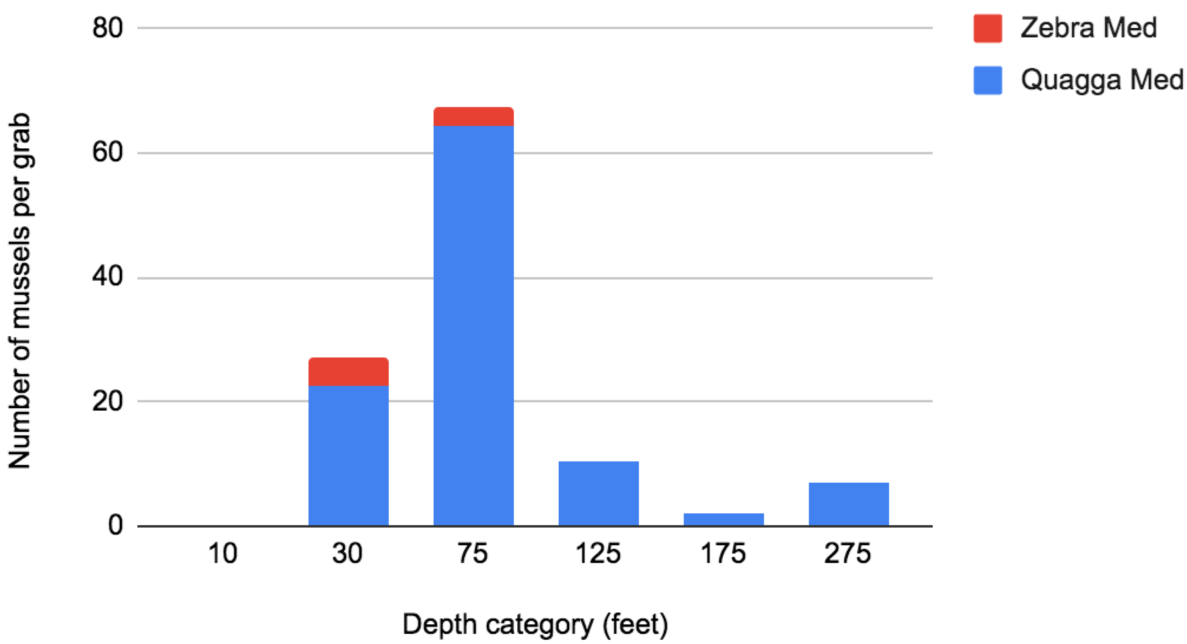

Figure 5: Median number of quagga mussels and zebra mussels per sample found at different depths

Out of the depths we sampled, we collected the least amount of mussels at the 10 foot depth (in fact we only collected 1 mussel total), about 20% of all mussels were found at the 30 foot depth, nearly 50% of mussels were found at the 75 foot depth, and about 30% of mussels were found above 100 feet. Even though mussels were consistently most common around 75 feet, as shown in Figure 6, the individual sample with the largest number of mussels was collected at the 125 foot depth at Deep Water Point. This suggests mussel distribution might be more uneven than our data show.

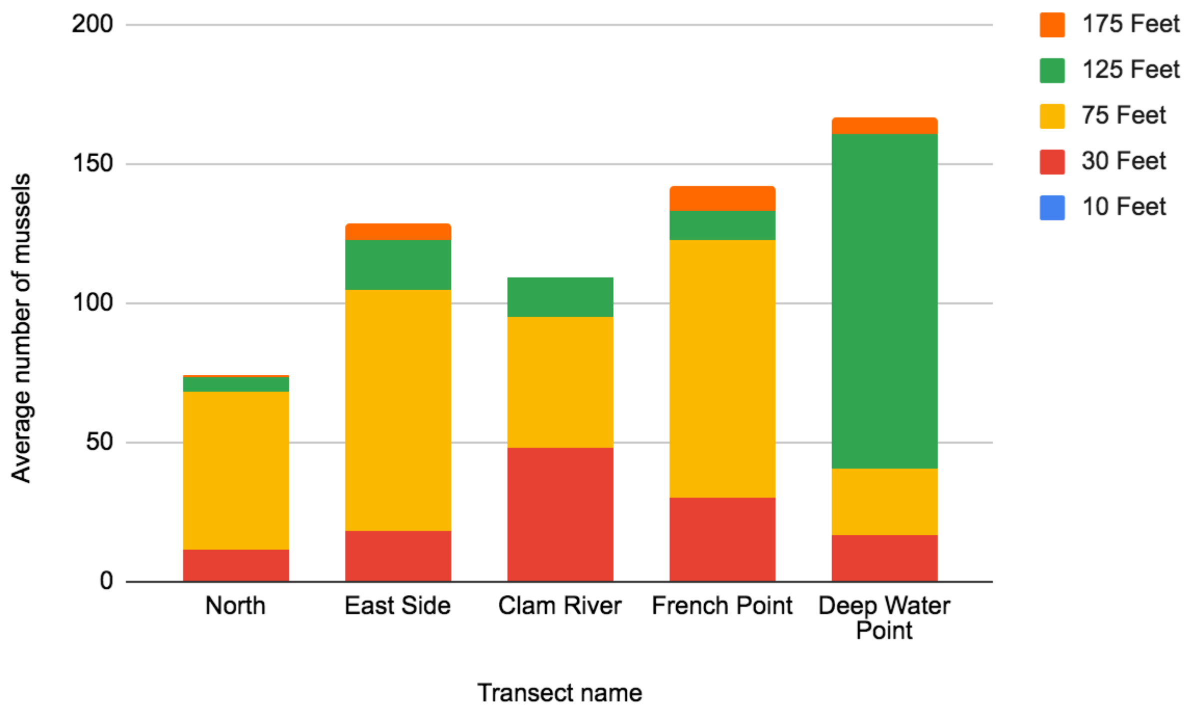

Figure 6: Average number of mussels per sample by depth and transect. Two samples are averaged for each depth, except for the East Side 175 foot location, which had only one sample. Transects are ordered from north to south.

Figure 6 shows that the North transect had the fewest mussels collected and the Deep Water Point transect, at the south end, had the most, with the other transects between the two in terms of mussel abundance. We see also in Figure 6 that the mussel distribution patterns by depth are very similar in different parts of the lake: 75 feet has the greatest mussel abundance, which is flanked by lower abundance at shallower and deeper depths. The one exception is Deep Water Point, where the 125 foot zone was the most abundant. We found 206 mussels in one sample here. This was 69% more than the next most abundant sample (at 75 feet), and over 5 times more abundant than any other sample at the 125 foot depth, so it created a very different pattern of mussel distribution by depth. Figure 7 shows how much of an outlier this data point was.

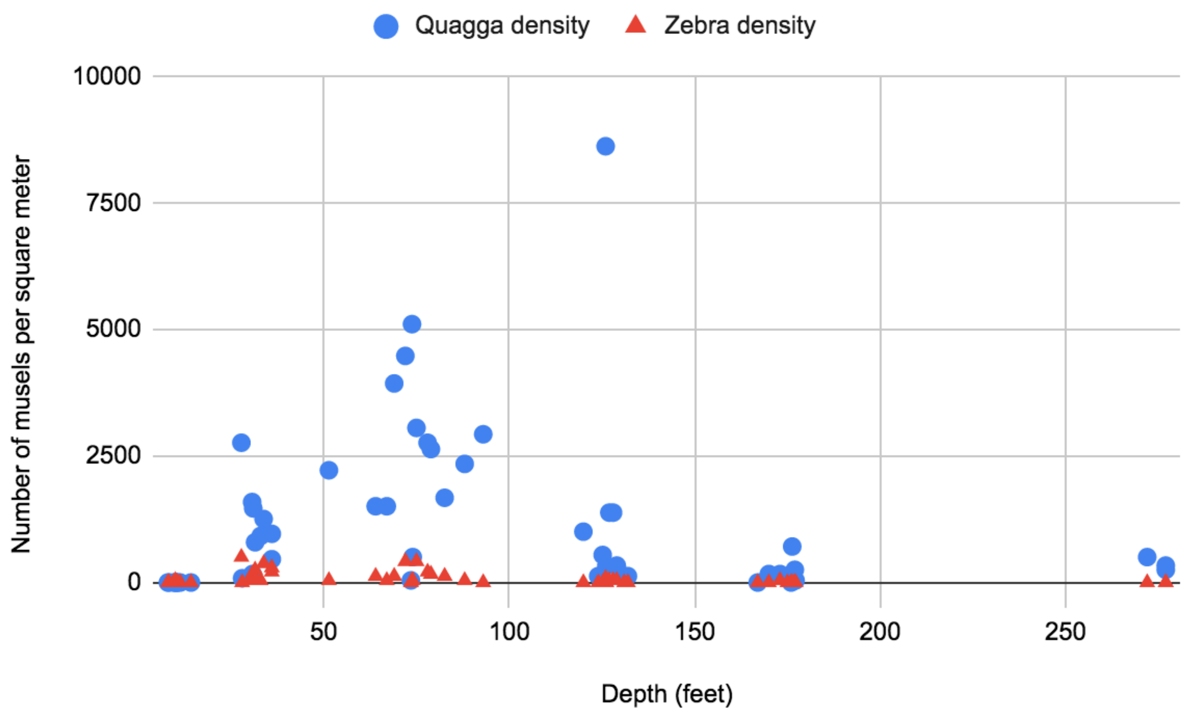

Figure 7: Densities (number/m^2) of quagga mussels and zebra mussels per sample in Torch Lake

Densities in Figure 7 are reported in number per meter square to better compare them to densities of mussels from other studies, including those in Lake Michigan, which is very geographically close to Torch Lake and has experienced dramatic ecological changes as a result of quagga and zebra mussels. Almost all quagga mussel densities in Torch Lake were found to be below 5,000/m^2, and in depths other than 75 feet, the densities were often below 1,500/m^2 (Figure 7). All zebra mussel densities were at or below 500/m^2.

We also calculated density as mussels per square inch because many of us can better visualize a square inch than a square meter (Table 1). However this is a non-standard way of reporting and doesn't indicate that every square inch looks this way. You will also note that we report fractions of a square inch, to indicate that there is less than a whole mussel per square inch, or in other words that you'd need to look at more than one square inch to find whole mussels. Although there is sometimes a big range (Table 1), this colloquial, summative description is nevertheless informative about the spread of the data.

The range of mussel density was the smallest in the 10 foot depth (0.03/in^2), and greatest in the 125 foot depth (5.64/in^2), however, without the one extreme data point, the range at 125 feet would be only 0.86/in^2. This amount of variability suggests more sampling at the 125 foot depth is warranted. The highest average mussel density was at 75 feet (1.71/in^2) (Table 1).

Table 1: Summary statistics for mussels per square inch at each depth. 10 measurements per depth, except for 175 feet (9), and 275 feet (3). *number greater than zero

Depth (feet)	Median	Average	Minimum	Maximum	Range
10	0	0.00*	0	0.03	0.03
30	0.63	0.69	0.06	1.83	1.78
75	1.79	1.71	0.03	3.39	3.36
125	0.29	0.93	0.08	5.73	5.64
175	0.06	0.11	0	0.47	0.47
275	0.26	0.28	0.19	0.38	0.19

In 2000 in Lake Michigan, quagga mussel densities below 30 meters averaged 57/m^2, and increased to 7,547/m^2 five years later (Nalepa et al., 2014). Densities in deeper depths expanded even more dramatically (Nalepa et al., 2014). By 2015 Lake Michigan was primarily lined in quagga mussels that were found to have a density between 1000/m^2 and 10,000/m^2 (royal blue in Figure 8).

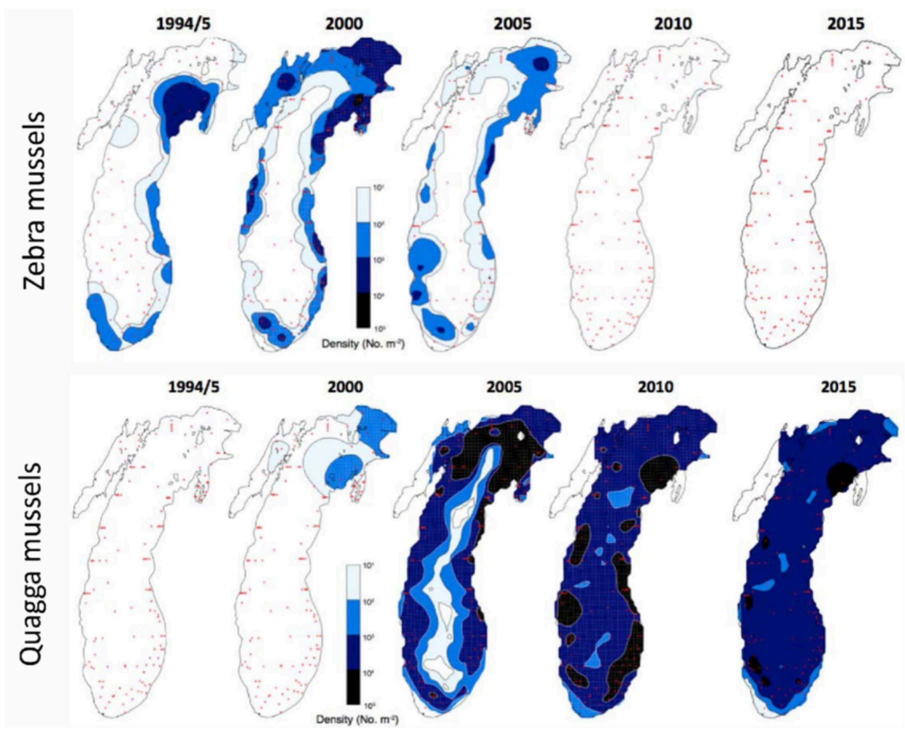

Figure 8: Density of zebra and quagga mussels found in Lake Michigan from 1994-2015. Density categories are in a logarithmic scale: 10-100/m^2, 100-1000/m^2, 1000-10,000/m^2, and 10,000-100,000/m^2 (From Nalepa et al 2014 (1994-2010) and Mehler et al 2020 (2015))

In Torch Lake, we found that 36% of the sample locations had an average quagga mussel density of 1000-10,000 mussels/m^2 (Figure 9), which is the density over the majority of Lake Michigan in 2015. There were no areas in Torch Lake with mussel densities in the highest category, over 10,000/m^2. 39% percent of the sites had a quagga mussel density between 100 and 1000/m^2, and 7% had a quagga mussel density below 100/m^2(Figure 9).

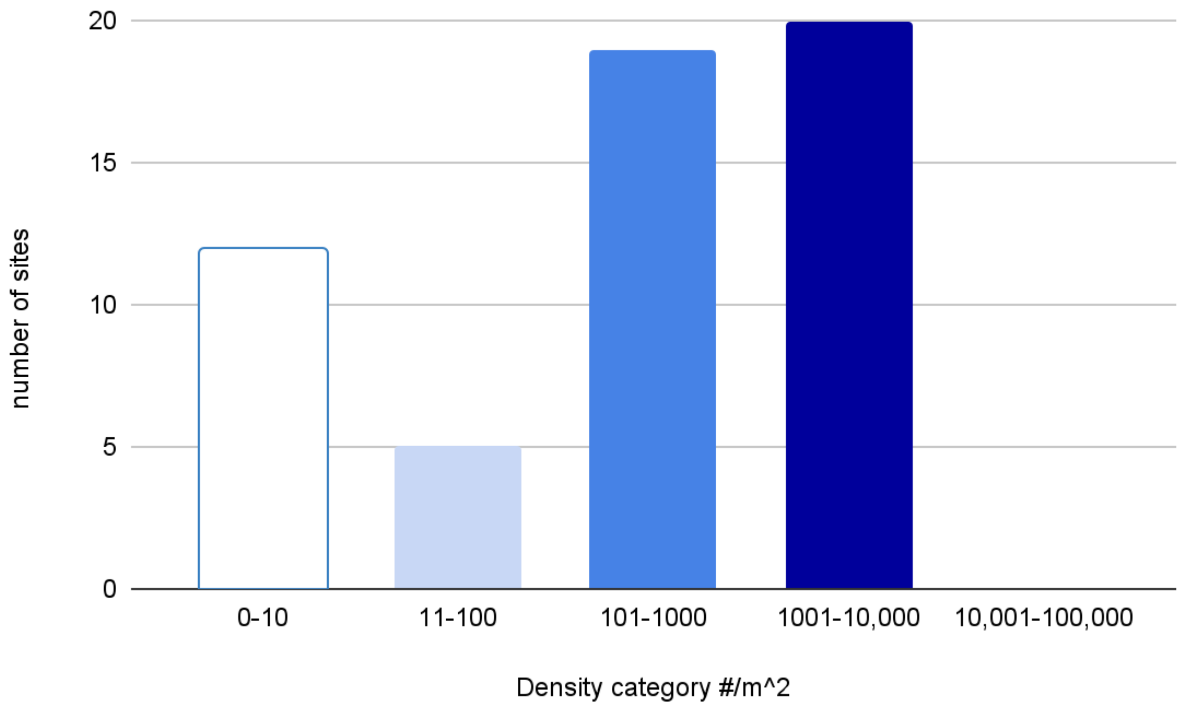

Figure 9: Average density of quagga mussels for all sites in Torch Lake

The highest average density in Torch Lake is around 75 feet, at 2,572 mussels/m^2 (Table 2). The next highest average is around 125 feet, which also displays the highest variability.

Table 2: Average density (± SE) of quagga mussels by depth in Torch Lake. Each depth category had 5 sites. Each site had two samples, which were averaged, except one site at 175 feet, which had only one sample. There were only three samples collected at 275, which were averaged.

Depth category (ft)	Average density (#/m^2) ± SE
10	0.0 ± 0.0
30	1,047.5 ± 271.9
75	2,572.7 ± 531.1
125	1,399.5 ± 905.9
175	171.8 ± 66.4
275	363 ± *n.a.*

Density can be interpreted better with accompanying information on size of mussels. Mussel size gives a rough indication of the activity of the mussels, both their reproductive activity, and their filtering capacity. The length of quagga mussels we collected ranged from under 5 mm to 35 mm. Quagga mussels ranging from 30 to 35 mm were the least common, appearing in just 4 samples (Figure 10).

We did not find any zebra mussels that were 25 mm or larger. However, since we collected so few zebra mussels relative to quagga mussels, it is difficult to make comparisons between species.

Quagga mussels smaller than 10 mm took up 42% of all mussels collected (Figure 10). Since mussels can reproduce at 8-9mm, some of these were large enough to reproduce, moreover it is certain that the remaining 58% were large enough (>10mm) (Figure 10).

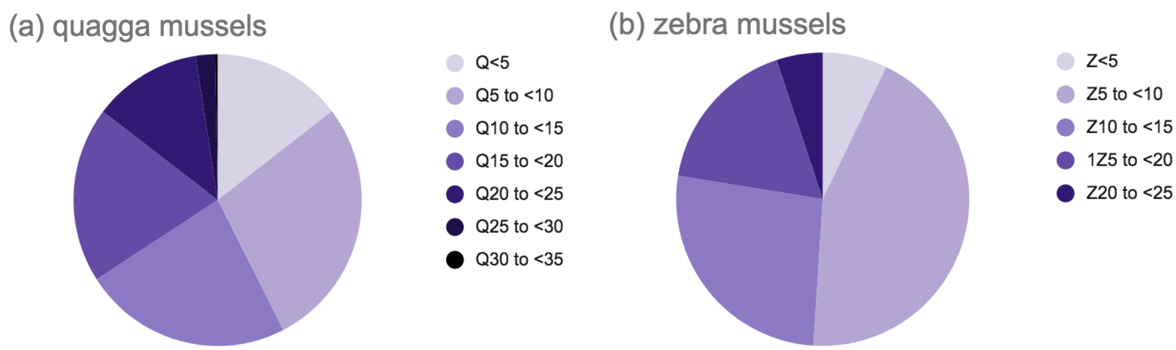

Figure 10: Percentage of of quagga mussels (a) and zebra mussels (b) found in each size category (mm)

We estimate that there are about 30 billion quagga mussels in Torch Lake. The volume of Torch Lake is 3.25 trillion liters, so it would take just over two weeks to filter all of the water in Torch Lake if every mussel were filtering one liter of water each day (and the water was evenly circulated). Since we know all of the mussels we collected were not mature, the time it would take to filter all of the water is more than this.

If 60% of the mussels were mature (greater than 8mm long), it would take about 26 days for these mussels to filter all of the water. However the smaller mussels are doing some filtering and these calculations exclude zebra mussels entirely, so 26 days is probably still a conservative estimate. Yet, even if there are half as many mussels as we estimate, the entirety of Torch Lake would still be filtered at least six times per year (assuming a well mixed lake, which Torch is not for many months each year).

To compare, it is estimated that the quagga and zebra mussels in Lake Michigan could theoretically filter the entire lake in two weeks.

Conclusion

We found vastly more quagga mussels than zebra mussels. 94% of the mussels collected were quagga mussels. This is not unexpected as zebra mussels cannot thrive on soft surfaces and the bottom of Torch Lake is mostly sand, clay, and silt beyond the shallows (Tip of the Mitt Watershed Council, Torch Lake). It is also the pattern we see in most lakes that are inhabited by both zebra and quagga mussels: quagga mussels become dominant (Strayer et al, 2019; Karatayev et al, 2021).

The mussels in Torch Lake are most common at 75 feet. We found nearly 2.5 times the number of mussels in that depth as compared to the next most common depth of 30 feet (Figure 5). We are not certain as to why this happens. It could be because the 75 foot depth is steeply sloped, it is farther away from wave action, but still receives light and oxygen. Almost no mussels were collected at 10 feet, even though there were many mussels visible close to shore in water ≤4 feet (where we explored, but did not collect). Along the shore, rocks and other hard surfaces such as docks provide secure attachment points. Perhaps in the deeper 10 foot waters, wave action stirs up the loose sand too much for the mussels to stay in place? We do not know.

Mussels were also common in deeper depths, 125 ft and beyond. We almost always collected mussels there, and sometimes in large numbers. This is not surprising as Lake Michigan, which is much deeper, supports very high densities of quagga mussels even at its deepest depths. This suggests that the deepest depths in Torch Lake are very habitable for quagga mussels and could still experience a big increase in quagga mussel density in the years to come.

The densities in Torch Lake were quite high in some places, near $4000/m^2$ at 75 feet and $5000/m^2$ at 125 feet, however the averages are still a fraction of the densities experienced by Lake Michigan at its maximum, and many locations in Torch Lake have quagga mussel densities below $500/m^2$ (and as low as $21/m^2$). That is not reason to breathe a sigh of relief however because it is very likely that the mussel population is still growing and that Torch Lake has yet to see its maximum densities. Every lake experiences its own trajectory with quagga mussel population dynamics (Strayer, 2019) but, deeper lakes tend to see higher maximum densities than shallower lakes (Karatayev et al., 2021), so Torch Lake would be in the camp to experience these higher densities, perhaps approaching those of Lake Michigan.

This study shows that the quagga mussel population in Torch Lake could be large enough to cause a change in the nutrient distribution of the lake. It is well documented that *Dreissenid* mussels impact nutrient distribution in lakes (Karatayev et al., 2021 and Li, et al., 2021), so further study into the dynamics in Torch Lake would be worthwhile.

We cannot make a conclusion or inference about how *Dreissenid* mussels influence the presence of GBA based on the data we collected. We did find GBA at 10 ft, but very few mussels were collected there, and we noticed no particular correlation.

We found a variety of sizes, but 51% of zebra mussels and 42% of quagga mussels collected were small (<10mm) (Figure 10). Smaller mussels tend to be younger. A larger proportion of mussels being younger suggests that they have not been in the lake for long; another piece of evidence to suggest this population is likely growing.

Discussion

This study is vital for the local communities around Torch Lake because a significant portion of their economy is based on tourism. If the lake is in distress, the economy could also potentially be in distress. These mussels have the potential to damage the lake by draining the nutrients out of the water column and depositing them on the bottom of the lake. The potential of concentrated nutrients in the lake would allow for certain organisms, like algae, to grow abundantly and impact the lake's beauty, potentially changing the water color from a pool-like blue to a browner or greener color. This possibility has already started with the arrival of GBA. This study is significant because this is the first time anyone has completed a scientific study on quagga mussel densities in Torch Lake. The information gained can help the greater scientific community understand more about quagga mussels and possibly GBA growth in Torch Lake.

Unfortunately, our data shows that quaggas are here to stay. We have estimated that there are roughly 30 billion quaggas in Torch Lake and we know that they are found in almost every depth and part of the lake. This isn't a good thing for the lake because a single quagga mussel that has reached reproductive maturity (8-9mm) filters about a liter of water a day therefore 30 billion mature mussels should be able to filter roughly 30 billion liters of water each day, which is the entire volume of Torch Lake in about three and a half weeks. This could be an overestimate, but even if the true number is half this, it is still a lot.

The results from our study are unfortunate for the ecosystem of Torch Lake. There are more mussels than we feared and the sheer number of them would prohibit removal. They eat plankton and tiny bits of algae out of the water column and they deposit their waste which contains lots of nutrients. This could be why golden-brown algae has become more prevalent in the last few years due to a nutrient buildup on the bottom, or even a nutrient depletion in the water column. However, we didn't specifically look for evidence that points to a relationship between quagga and zebra mussels and GBA so no conclusions can be drawn at this time.

This buildup of quagga mussels could possibly affect local residents and their property values as well as the economy around the Chain of Lakes watershed and Torch Lake. Because Torch Lake is one of the biggest tourism draws in northern Michigan, reduced water quality would be bad for the tourism industry. The impact of a changing ecosystem could also decrease the value of houses on the shores of the lake.

One thing we noticed during our sampling was that most of the mussels we collected were mature, ranging in size from around 10-15 mm to 15-20 mm (Figure 10). Yet, these mussels can grow to sizes greater than 35mm. 42% of quaggas were less than 10mm. This indicates a growing population. Quagga mussel populations can grow quickly because a single mature female can have about 30,000 successful offspring per year. If every year these mussels are continuing to multiply then the population could soon reach very high densities. From quagga mussel density data in Lake Michigan (Figure 8, Nalepa et al 2014), we see that quagga mussels can reach densities ten times what we found in Torch Lake. This shows that there is lots of room for mussel densities in Torch Lake to continue to increase.

There were very few issues with our data collection. Thunderstorms, waves, and wind would occasionally cause the Ponar to deploy at an angle, potentially impacting the number of mussels collected. However, we know our drops were successful because we took GoPro footage of every drop, so we could tell if the Ponar tipped or spun around. We eliminated unusual drops from our dataset.

There was only one occasion when we were unable to get a second sample during Ponar grabs, at 175 feet on the east side transect, so this location was represented by only one drop. Lastly, the Ponar function itself may have impacted results because when it hit the bottom it would often push some of the potential sample away. Again, this is why the video footage is so valuable, and analyzing it is recommended.

We also know that some of the tiniest mussels were lost to screen size, but we didn't expect such small mussels and in the interest of time, the bigger screen size was necessary. Using a screen with a smaller mesh could prevent the mussels from falling through and give a more accurate count.

Our team has some suggestions for future research. Our first suggestion is to investigate the connection between GBA and quagga mussels. This wasn’t the focus of our study but TLA has been investigating the causes of GBA for many years and holds the attention of many Torch Lake residents.

The next suggestion is to look into why there are no quagga mussels in the shallow sand flats, around 10 feet. We noticed that there was a strange lack of quagga mussels here even though they were abundant on the rocky shoreline and at 30 feet. We formed a hypothesis that the lack of mussels was due to wave action and potential boat traffic.

Another suggestion is to develop a more accurate estimation of the number of quagga mussels in Torch Lake. In this report, we used broad averages for depth and density, but an analysis using the area of Torch Lake bottomland at different depths would be more accurate.

Our final suggestion is to examine the video footage in greater detail. There is a video of every drop taken at 125 feet and shallower, which could be used to validate the Ponar data.

Additionally, the video footage, including the two transects we recorded, reveals large expanses of mussels that looked like carpets, which might yield additional valuable information.

There's a danger of accidentally making this quagga problem much worse by adding extra nutrients to the water. Even though quagga mussels remove nutrients from the water column, they do not remove them from the lake, so every precaution must continue to be taken to prevent excess nutrient additions. The No Fertilization campaign should continue to try and prevent nutrient additions.

There should be an increase in public awareness of the Clean, Drain, Dry initiative, especially for tourists, to try and prevent the mussels from spreading to other lakes or streams in the area. Although not much can be done about the mussels in Torch Lake, we hope this study will be a lesson to residents and visitors: we can prevent ecological damage if we change our behaviors to ones that support ecological health. We can still prevent the next invasion.

The public should be made aware that they cannot help the native species by removing them from their native habitat and trying to raise them in a man-made controlled environment. This would actually be incredibly detrimental to them and potentially kill them or cause defects that don't normally occur. The best way to save our species is to let them take care of themselves by supporting the environmental conditions that allow them to thrive.

There needs to be a campaign that shows people that these mussels are in the lake in huge numbers despite not being able to see them off the end of the dock or in the easy-to-see areas like on a sandbar or at the beach. Finally, many people still don't know the difference between a quagga mussel and a zebra mussel, and we know that the more people know, the more they care. The biggest reason that the public needs to be educated is that if they don't know about the problem then they might inadvertently make the problem worse.

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We want to thank Gary Bart, Alyssa Cogan, and Jeanie Williams for guiding us daily. And to Lois Maclean and Steve Laurenz for coming out with us on the boat. We also want to thank Steve Laurenz for loaning us his GoPro camera. It was indispensable for helping us learn what is really happening at the bottom of the lake.

A big thank you goes to Beth LaVasseur for helping us with all parts of writing the report, including bringing her TV to the Shanty Creek Beach Club and for reserving that space for us. Thank you also to Shanty Creek Beach Club for letting us meet in your club house through all of August so we could write our report.

Our boat captains, Brian Hayes, Bob Milliron, and Greg Fredericksen kept us safe, while also giving us great adventure in all parts of Torch Lake. We are especially grateful to Julie Hayes for picking us up at the Torch Lake Yacht Club in the pouring rain and bringing us back to her house for pizza. Thank you Beth for the pizza!

Peggy Dolane visited us while we were writing our report and we appreciated learning about how things used to be on Torch Lake. We also want to thank the Wierda family for providing the funding for this experience. It means so much that this family wants to encourage young people to love Torch Lake as much as Mr. Wierda did.

We also thank Paddle Antrim for providing us with invasive species field guides.

Finally, we thank our schools, teachers, and school boards for supporting this work, encouraging us, and giving us rides. It was a great summer.

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APPENDIX 1: About this study

This study was designed by Jeanie Williams with the guidance of Dr. Jan Stevenson, Dr. Harvey Boostsma, and the TLA Water Quality Team. Equipment was designed and built, when necessary, by Gary Bart. The work was performed by three high school students (all rising juniors), with daily support from Alyssa Cogan (rising junior studying Environmental Studies and Sustainability at Michigan State University), Gary Bart (Internship Lead for TLA), Jeanie Williams (Internship Coordinator), and our boat captains (Brian Hayes, Bob Milliron, and Greg Fredericksen). Lois McLean (TLA Executive Director), Steve Laurenz (TLA Education Chair), and the TLA Water Quality Team also provided support from time to time.

The three students did the Ponar hauling, sieving, measuring, and counting. They also guided our direction daily and were instrumental in designing our activities for the second half of the summer. The data analysis was performed by Jeanie, with assistance from the interns. The students wrote the bulk of the report; Alyssa, Beth LaVasseur (Volunteer) and Jeanie supported their writing. Jeanie did final edits and added additional information for clarity and to deepen the analysis somewhat.

The TLA internship program is intended to introduce young people to the field of aquatic science and help them build a foundation of skill and experience, as well as a deeper personal connection to the waters that they live among. We hope that through this experience, these young people will be better equipped for whatever they choose to do next. For some it will be a career in conservation or environmental science. For others, they find that their interests lie elsewhere. We mostly discover what we like to do by doing lots of different things, and this experience is distinctive and clarifying. No matter what the students pursue next, for all of them, they learned many things about how aquatic systems work, and what it really means to protect water bodies. And they left with an experience that will always mark their lives and connect them to the place where they grew up.

We also aim to focus the TLA internship around a real question that would be helpful to answer. In an ideal world, the students learn a lot *and* TLA gets useful data that it can use to better educate the community and protect the lakes. In this case, the question at the heart of the study was particularly interesting to TLA and the community at large. We learned a whole lot about quagga and zebra mussels, but largely in a qualitative way. Yes, we are reporting numbers and counts, but we didn’t run statistical analyses on them, and our sample sizes were small, so citing numbers to make arguments and such probably won’t be the best use of this work.

We discovered something very important, and we made hard decisions all along the way to make sure the project could be completed in the time we had (six mornings on the lake), and the capabilities available (three typical 15-year olds, albeit smart, ambitious and wonderful in marvelous and excellent ways).

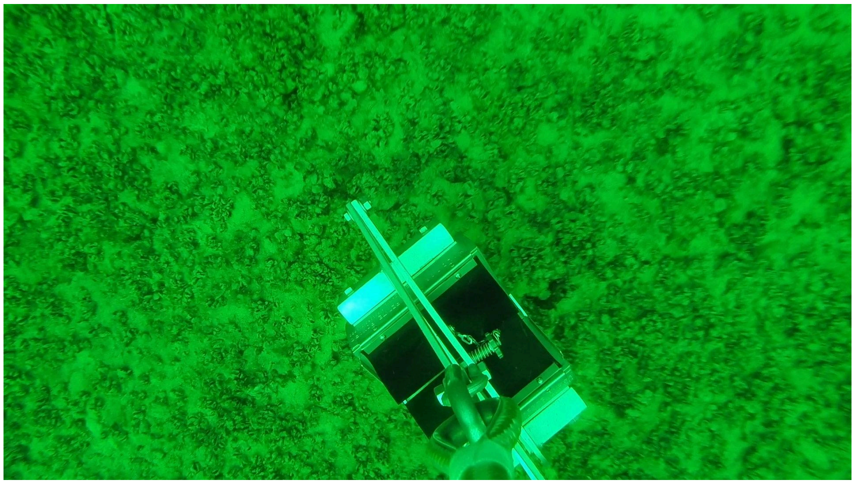
We hope you take this work seriously, as it is a well designed and robustly implemented study, but like all studies, there are limits to how far it can be applied.

APPENDIX 2: Photos

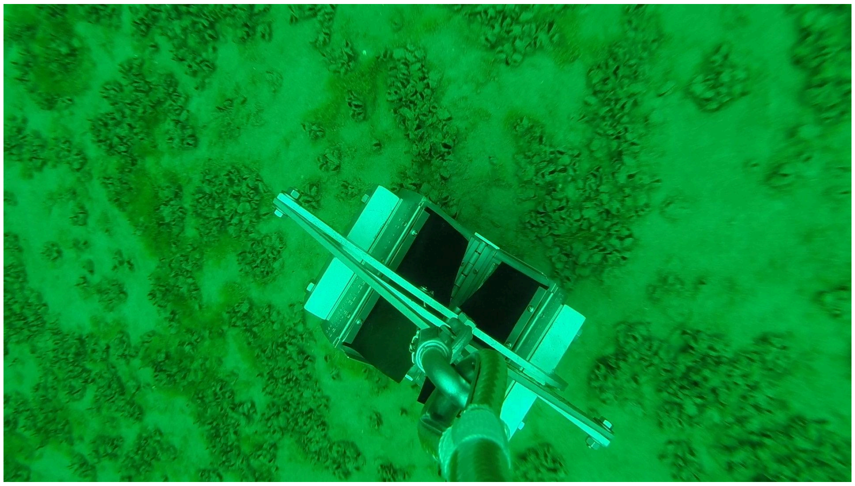
Alyssa Cogan made a slideshow that compiles photos from our summer together.
Click here to see images

Example still-frames from GoPro footage. All of the bumpy stuff is mussels.

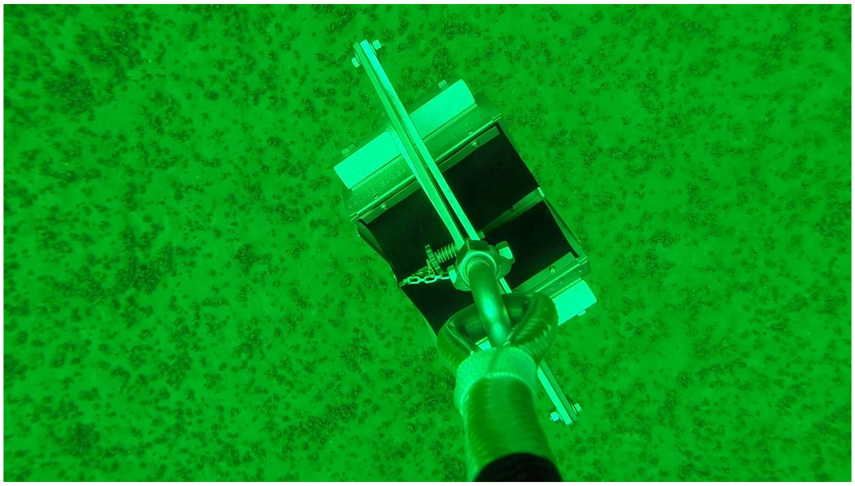
North Transect, 75 feet



Deepwater Point Transect, 75 feet



French Point Transect, 75 feet



APPENDIX 3: Presentation

The students presented their work to the TLA Board of Directors as a team. They also presented individually to their school's Board of Education.

Click here to see the presentation slides

APPENDIX 4: Data

Here you will find our raw data.

For additional data analysis and graphics, Please contact Jeanie Williams: jeanie@wayfinderfacilitation.com

Click here to explore the map of the 2023 data, as well as the data set from the 2022 interns. To the right is a screen shot of the map you will find.