Lake Tahoe East Shore Asian Clam and Metaphyton Delineation and Control

FINAL REPORT

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Introduction

The Asian clam (*Corbicula fluminea*) is one of many aquatic invasive species established at Lake Tahoe. Since its first documentation off Nevada Beach in 2002, the Asian clam population (hereafter referred to as AC) rapidly spread along the entire south shore of Lake Tahoe, and gradually expanded north to Glenbrook Bay (Hackley 2008), with a more recent, expanding satellite population at Sand Harbor State Park (Allen et al. 2018). Coincident with the AC presence, there has been an increasing presence of metaphyton algae both in the water and washing up and decomposing on the shoreline (Figure 1).

The linkage between the presence of AC and the appearance of nuisance metaphyton has been scientifically established. Laboratory experiments by TERC (Wittmann et al 2013) conclusively showed that the excretions of AC had a 10-100x increase in concentration of both orthophosphate and dissolved nitrogen, above the ambient lake level. AC were in essence efficiently filtering phytoplankton out of the water, using a fraction of the filtered biomass to grow, and then excreting the remainder. This knowledge suggests two management approaches for limiting negative aesthetic impacts: 1) clam population control and 2) metaphyton removal after they have taken up the concentrated nutrients provided by the AC. The reduction of clam densities by deploying lake bottom barriers has been well documented (Wittmann 2012, Allen 2018, Senft 2019). While this method is effective over small areas (< 3 acres), it is time intensive, expensive, and creates its own aesthetic issues. It is also not a permanent solution, as AC will eventually return.

The Tahoe Environmental Research Center (TERC), in partnership with Nevada Division of State Lands (NDSL), implemented this project to assess the current state of the AC population and possible management approaches. To complete this work, TERC completed a number of tasks including: surveys to delineate the extent of the invasive Asian clam (*Corbicula fluminea*) along the east shore of Lake Tahoe and associated metaphyton (filamentous unattached algae) growth, pilot studies to determine the effectiveness of new metaphyton removal techniques, lab experiment testing the use of hydrogen peroxide (H_2O_2) as a clam control strategy, estimates of the likely extent and intensity of the environmental impact if no actions are taken, and make recommendations on a long term management strategy for preventing metaphyton from washing up on beaches. The following report is a summary of methods and findings for completed tasks and recommendations for future management actions.

Figure 1: Metaphyton algae onshore at a beach in South Lake Tahoe.

Methods

Study design and detailed methods for each of the project tasks are detailed below. Tasks include scuba surveys of five specific beaches to quantify the extent of AC and associated metaphyton; lake pilot studies designed to evaluate the effectiveness of metaphyton removal from the lake bottom; a laboratory study to quantify the impact of hydrogen peroxide on AC. Field work and laboratory experiments were conducted during summer, 2023.

Delineation of Asian clam population

Five beaches along the east shore of Lake Tahoe were selected as monitoring locations. The five sites chosen for monitoring were Incline Beach, Hidden Beach, Chimney Beach, Whale Beach, and Skunk Harbor. Scuba surveys were completed at these five sites to establish the extent and abundance of the clam population at each site. Predetermined transects were established parallel to shore and the high-water line (6229.1 ft elevation) to provide maximum coverage at each site. Site specific maps outlining scuba transects are available in Appendix 1. An example of scuba transects for the Whale Beach site is shown in Figure 2. A total of 20 transects were completed between all the sites. Dive surveys were completed from August 28 – 30, 2023. The water surface elevation of Lake Tahoe during the survey period was 6227.98 ft (8/28/2023; USGS gage height Tahoe City, CA).

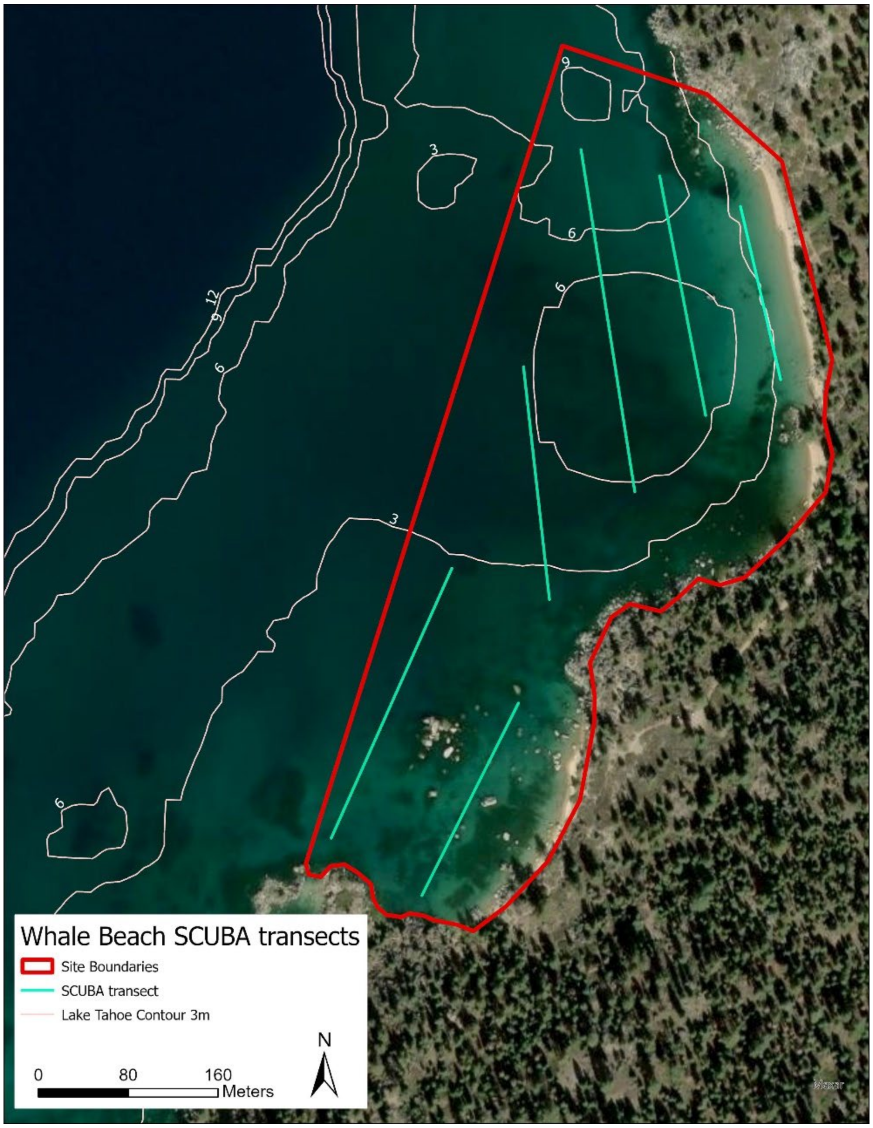

Figure 2: SCUBA transects completed at Whale Beach survey area.

Approximately every 5m, each dive team member sieved an area of about 0.04m^2 of sediment to a depth of ~15cm using a fine mesh (6mm) minnow trap. Clams were counted on site and noted on underwater data sheets so that changes in clam abundance would be known along each transect. Clam counts from each diver were averaged and are reported in Appendix 2. The clam count data from transects were represented as a "heat map" showing the relative abundance of clams across all the survey areas along the East shore (Figure 3).

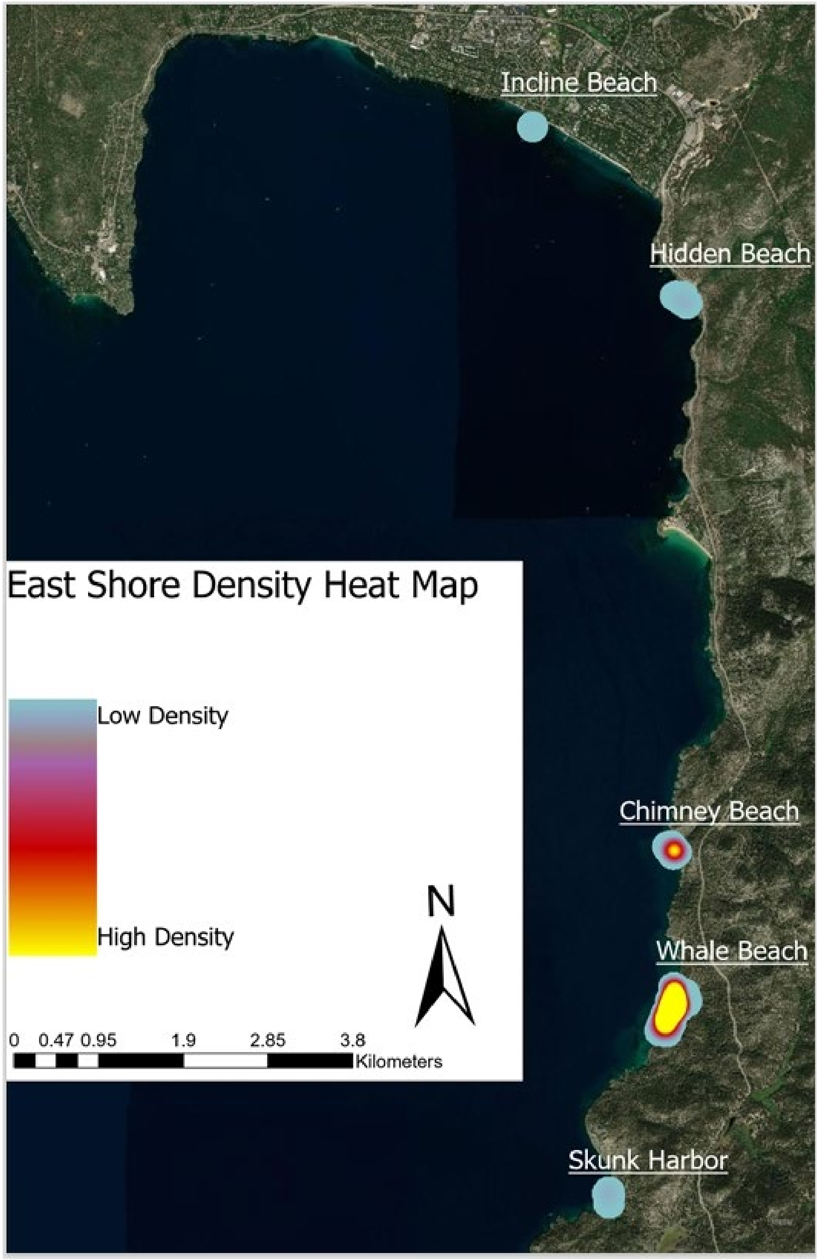

Figure 3: Dive transects clam abundance heat map for East shore survey locations.

Delineation of metaphyton algae

Metaphyton surveys were completed using divers and unmanned aerial vehicle (UAV) imagery. UAV monitoring at each site is a proven method using aerial imagery to map metaphyton growth inside the survey area. UAV flights were conducted during late summer to coincide with peak metaphyton growth. Additional metaphyton data was collected by divers while completing AC transects in the survey area.

The UAV was a DJI Phantom 4 Pro©. The Phantom 4 Pro is a quadcopter format consumer/professional grade UAV. The integrated 20 megapixel camera provides detailed imagery with a sufficient ground sample distance (GSD) for data acquisition. Flight planning and image capture were collected through ESRI Sitescan software. The standard 'lawnmower' flight path was executed to maximize coverage for mapping each survey area. Adequate overlap between flight paths ensured sufficient coverage of the designated survey area. These techniques have previously been used to assess metaphyton coverage along the southeast shore of Lake Tahoe (Hackley 2020).

Post processing and analysis of aerial imagery is completed using ESRI Sitescan® software. Images collected by the UAV are individually calibrated and geo-referenced in the initial pre-processing of the software. Images are then 'stitched' together using generated keypoints by the Sitescan software. Keypoints are matched between consecutive images, allowing for a seamless stitching of images into one large image. Generally, orthomosaic processing is difficult to complete overwater because of the homogeneity of a water body. However, due to the clarity of Lake Tahoe's water, images of the nearshore (<10m) can be successfully processed. Natural environmental factors such as submerged rocks and woody debris can positively affect the ability to successfully recreate an orthomosaic (additional reference points) while surface glare, turbidity, and dissolved organic matter (DOM) hinder the process. Therefore, the natural characteristics of the site in addition to weather and time of day can impact orthomosaic generation. Determination of percent cover of metaphyton at individual sites was evaluated using ArcGIS Pro®. Completed orthomosaics are assessed in ArcGIS Pro and used to determine metaphyton coverage within the established survey area.

Metaphyton Removal

The metaphyton removal pilot study was completed to evaluate the effectiveness of removing metaphyton algae from the lake bottom prior to washing onshore. The pilot removal technique involved using a diver assisted suction pump with algae capture on a floating platform. The removal system included two main components; the surface platform and the in-water intake system. The surface platform was designed to pump (212cc water pump) algae up from the intake at 158 GPM and separate the algae from water. This was achieved by decreasing the velocity of the water entering the surface platform to facilitate the separation of algae using a mesh screen. The water intake system consisted of a circular metal intake connected to the surface unit by a 2 inch diameter flexible hose. A schematic of the metaphyton removal system is shown in Figure 4.

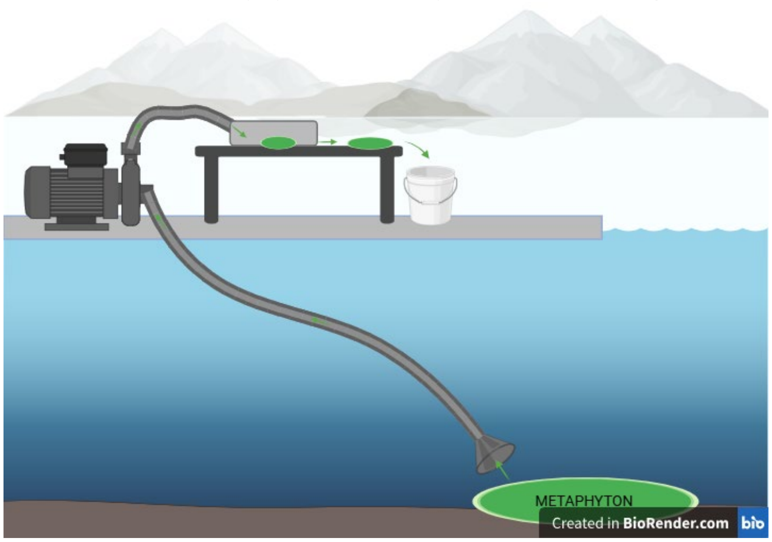

Figure 4: Metaphyton removal system schematic tested at Lake Tahoe.

Figure 5 and Figure 6 show the surface platform and the intake system during operations. Operations enabled the suction removal of metaphyton from the lake, essentially 'vacuuming' the algae off of the lake bottom.

Figure 5: Surface platform used to separate algae from water during the removal process.

Figure 6: Diver assisted intake system used to remove algae from lake bottom during the removal process.

Two areas were treated representing moderate to high levels of metaphyton growth. These two areas were selected near Lakeside Marina and Whale Beach, both sites along the East shore of Lake Tahoe. A 10m x 10m area was delineated and gridded into 4 quarters at each site. An example of the grid deployed at the Lakeside site can be found in Figure 7. Prior to the removal process, metaphyton algae samples were taken adjacent to the site to allow for physical and chemical analysis of algae. Pre-removal metaphyton coverage estimates were made of the area before beginning the removal process. The removal process involved divers guiding the suction intake to metaphyton concentrations, keeping the intake free of the bottom in care to not disturb the substrate (Figure 6). Metaphyton was pumped from the intake to a surface platform on the research vessel where it was collected and contained, allowing separated water to drain on site (Figure 5). Turbidity samples were taken throughout the removal process to monitor potential suspended particle impacts from the process. After initiating the removal process, divers completed the suction removal of metaphyton from the defined area one quarter at a time.

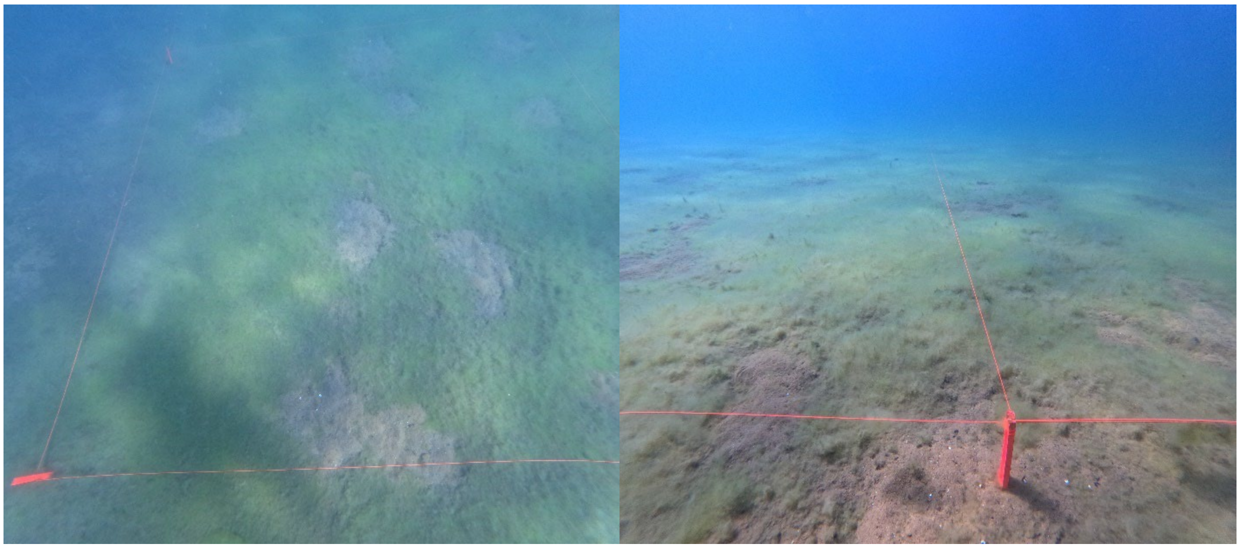

Figure 7: Metaphyton removal area grid before removal process at Lakeside site.

Hydrogen peroxide clam control

The laboratory study was designed to quantify the impact of hydrogen peroxide on Asian clams as a control method with the goal of advancing overall knowledge on the behavior and mortality of AC. UC Davis TERC has conducted several studies on AC populations and their effects in Lake Tahoe as well as the efficacy of management practices. However, there is currently limited information and research on AC mortality especially in fresh waterbodies. The experimental design prioritized options that replicate true environmental conditions and that consider feasible and efficient management actions.

Sample subject collection consisted of water, sand, and clams collected in Marla Bay, Lake Tahoe. The samples were sealed in buckets and carboys with secondary containment to ensure no unintentional transport of material. AC were provided a 7-day acclimation period to ensure adequate survival conditions in aquarium tanks. The acclimation period also confirmed samples were under stable condition at the onset of the experiment. Clams were evenly distributed to four separate 20L tanks (15 clams per tank) with incremental hydrogen peroxide concentrations of 0 ppm, 0.005 ppm, 0.5 ppm, and 50 ppm. Clams were monitored hourly over a 21-day exposure period for behavioral changes and mortality. The experiment design and set up is displayed in Figure 8.

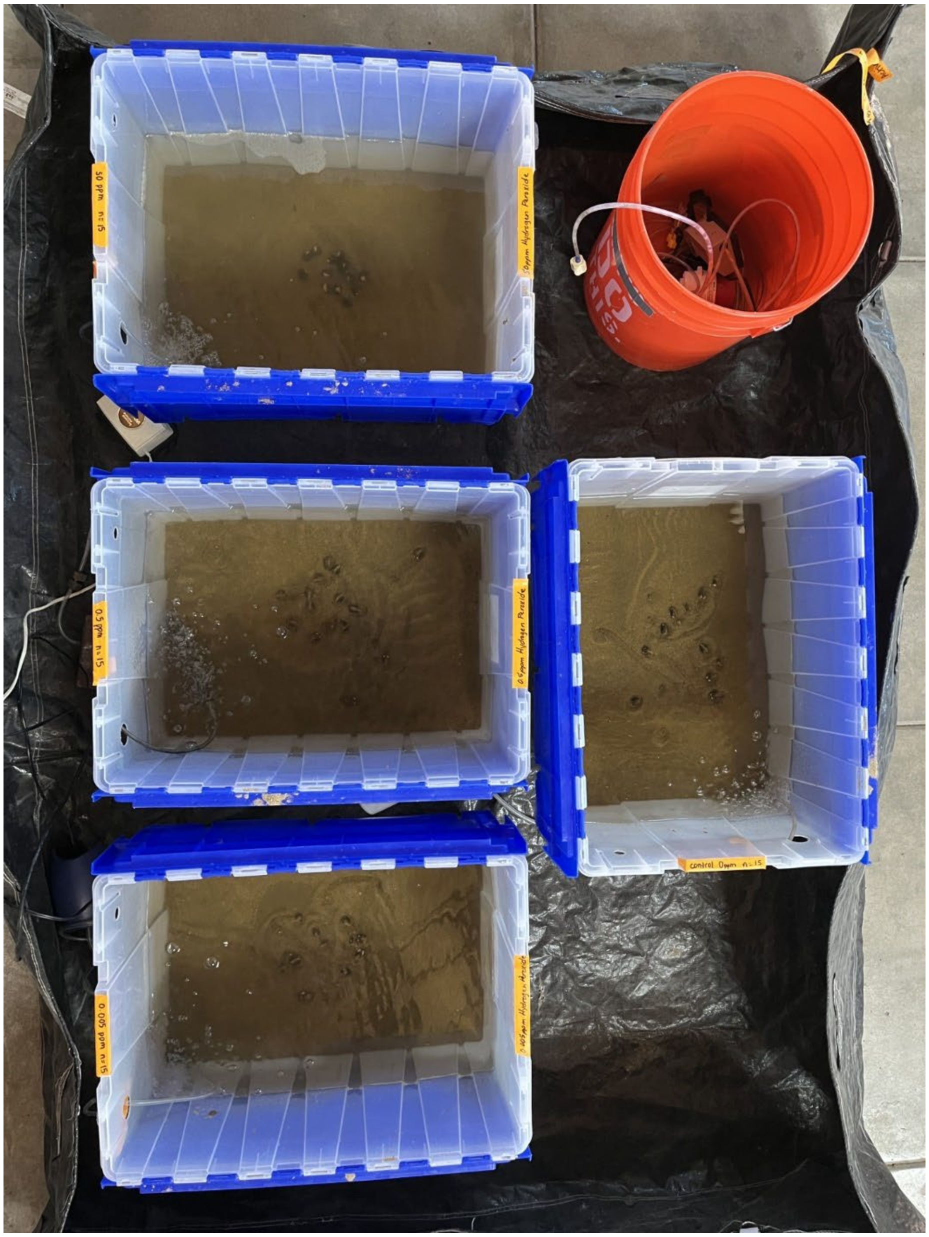

Figure 8: Hydrogen peroxide clam mortality experiment design.

Results

Delineation of Asian clam population

Scuba surveys conducted from August 28 – 30, 2023 detected varying ranges of clam populations in the survey areas of all five monitoring locations. At Incline Beach, only 1 clam was detected on the deepest transect at a depth of 5m. At Hidden Beach, 1 clam was detected on the deepest transect at a depth of 5m. During Hidden Beach transects divers noticed dead clam shells outside of the survey area, so another transect line was added in the field. Clams were detected throughout this transect in small numbers of 1 – 2 clams per count. At Chimney Beach, clams were detected in higher densities with up to 24 clams per count on the outermost transect. At Whale

Beach, clams were detected throughout the survey area with high densities along the deeper transects, up to 56 clams per count (Figure 9). At Skunk Harbor, clams were detected sporadically throughout the survey area in low numbers, 1 – 3 clams per count. Transect AC count data for each site is available in Appendix 2. A web map containing geographic data on clam counts from the completed surveys is available in Appendix 5.

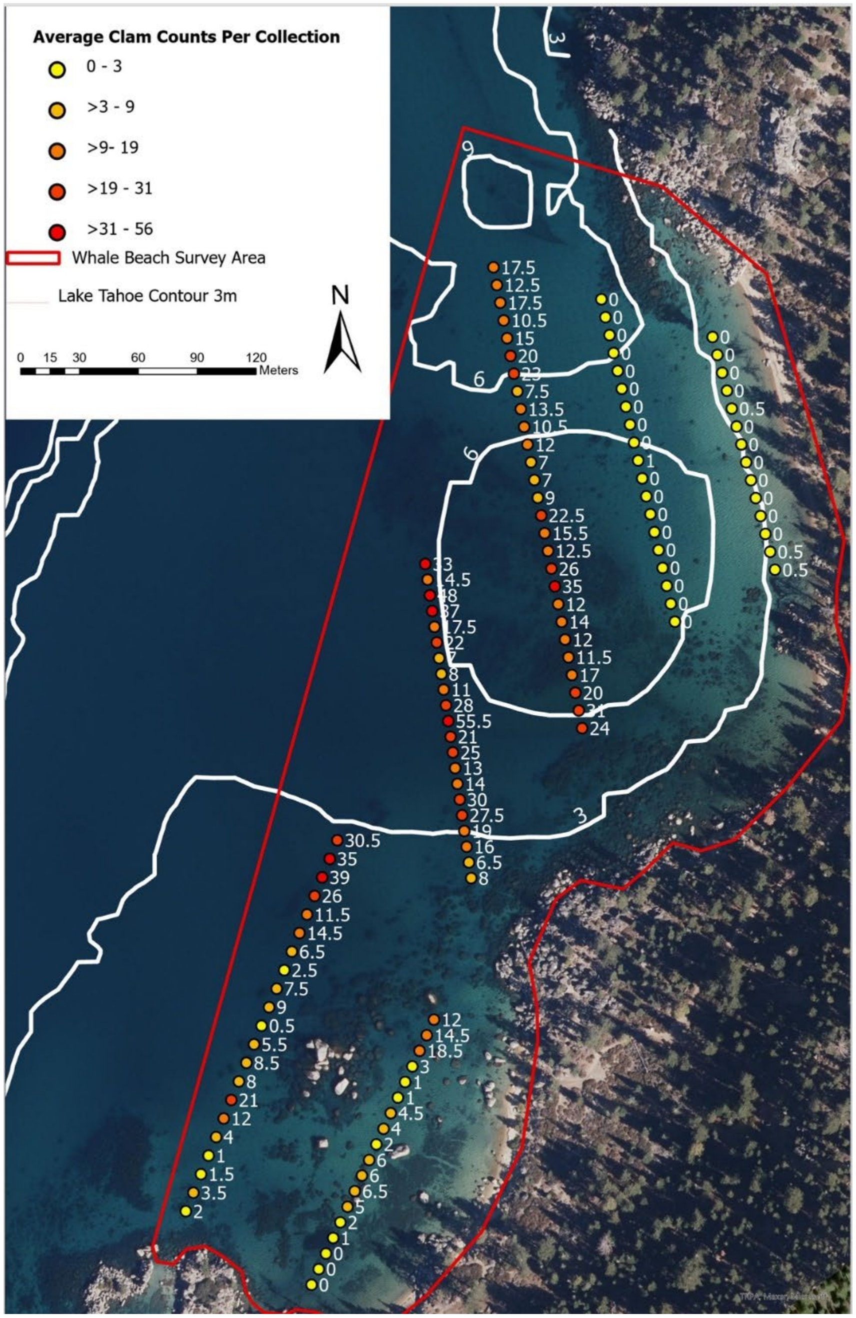

Figure 9: Transect clam count data for Whale Beach survey area.

With the exception of Sand Harbor, the extent of AC populations north of Glenbrook Bay have not previously been quantified despite anecdotal reports of clam presence and metaphyton algae along popular, and previously pristine, recreational beaches. AC population data from these surveys provide evidence that clams have continued to spread along the East shore of Lake Tahoe. Population densities vary greatly between sites providing insight into sites that have well established AC populations versus sites where populations are in early stages of forming. Incline Beach, Hidden Beach, and Skunk Harbor all contained clams but in very low densities indicating clam populations are new to the area and in early stages of establishment. Chimney Beach and Whale Beach contained clam count data in much higher numbers indicating well established populations at these locations. While all the beaches surveyed are popular recreational beaches, there are differences in recreation and visitation that may provide insight into the different stages of clam populations. For example, Whale Beach receives much of its visitation through watercraft. Satellite populations of AC within Lake Tahoe are thought to have been transported through watercraft as the main vector. This hypothesis is supported by higher densities of clam count data at sites such as Whale Beach and Chimney Beach which are frequented by watercraft. Transport to other locations may be influenced by similar anthropogenic vectors and/or environmental vectors such as lake currents.

Despite containing variable densities, all survey sites did exhibit AC populations in some form, and it is expected that these populations will continue to proliferate if left unchecked. AC populations and any associated secondary effects, including metaphyton algae, will continue to impact popular beaches along the shore of Lake Tahoe. However, these surveys are a necessary first step in mitigating negative effects associated with AC and preserving Tahoe's iconic recreational beaches along the East shore of the lake.

Delineation of metaphyton algae

Metaphyton surveys were completed using divers and unmanned aerial vehicle (UAV) imagery to delineate the extent of metaphyton algae at each site. Divers reported metaphyton growth at two sites while completing underwater transects. Chimney Beach contained small amounts of metaphyton located around the deepest transect at a depth of 10m. Whale Beach contained significant metaphyton growth at many areas inside the survey area, with increased observations at depths of 7 – 10m.

Orthomosaic imagery of survey areas was completed to estimate spatial coverage of metaphyton growth at each site. Orthomosaic imagery data for each site is available in Appendix 3. Whale Beach was the only site with sufficient metaphyton growth to map spatial coverage through UAV imagery. Whale Beach was estimated to have 24324 m^2 of metaphyton throughout the site area. Figure 10 displays the metaphyton coverage at Whale Beach with metaphyton represented as bright green.

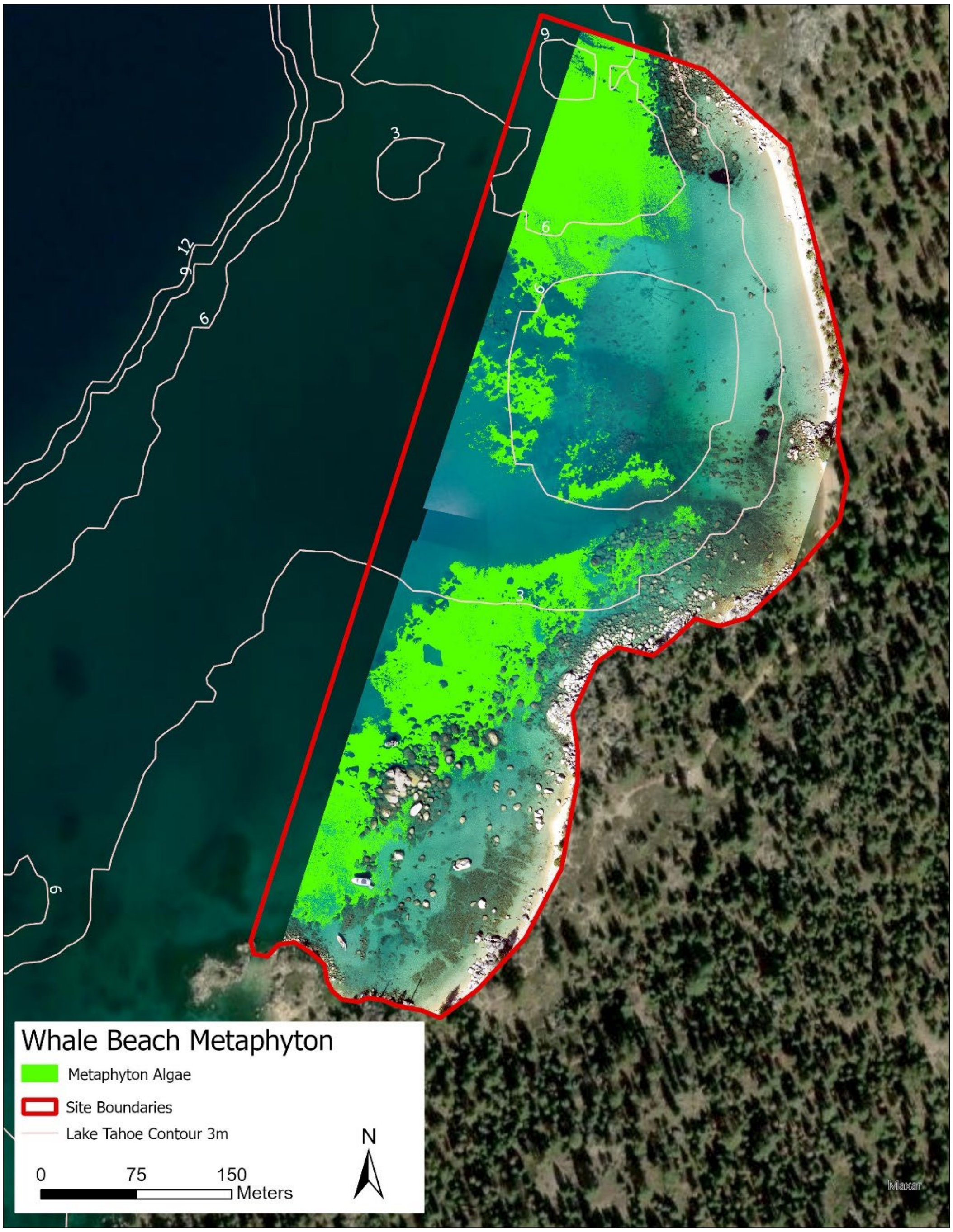

Figure 10: Metaphyton coverage at Whale Beach survey area.

Metaphyton algae was not present in measurable amounts at four of the five sites during surveys. Decreased metaphyton growth was observed throughout the entire nearshore of Lake Tahoe in 2023 (Smitts et al., 2024). The reduction in metaphyton was likely related to the abnormally large precipitation during the 2023 water year and related increases in the water surface elevation of Lake Tahoe. Lake Tahoe's water surface elevation increased by over four feet when compared to the previous year (USGS). The increase in lake level could have impacted AC activity and/or transport of metaphyton algae during the summer of 2023. It is expected that metaphyton algae will continue to proliferate at locations with high AC densities despite the decrease in 2023.

Metaphyton Removal

The metaphyton removal pilot study assessed the effectiveness of the developed in-situ, diver assisted metaphyton removal technique. The technique was implemented at two different sites, near Lakeside Marina (119.95383°W, 38.96082°N) and Whale Beach (119.93510°W, 39.14798°N). The Lakeside treatment area (10m x 10m) was estimated to have 90% metaphyton coverage, or 90m^2 of metaphyton (Figure 11). Whale Beach treatment area was estimated to have 50% metaphyton coverage, or 50m^2 of metaphyton. Metaphyton coverage estimates are calculated using image classification in ArcGIS pro (Smitts, A., 2024).

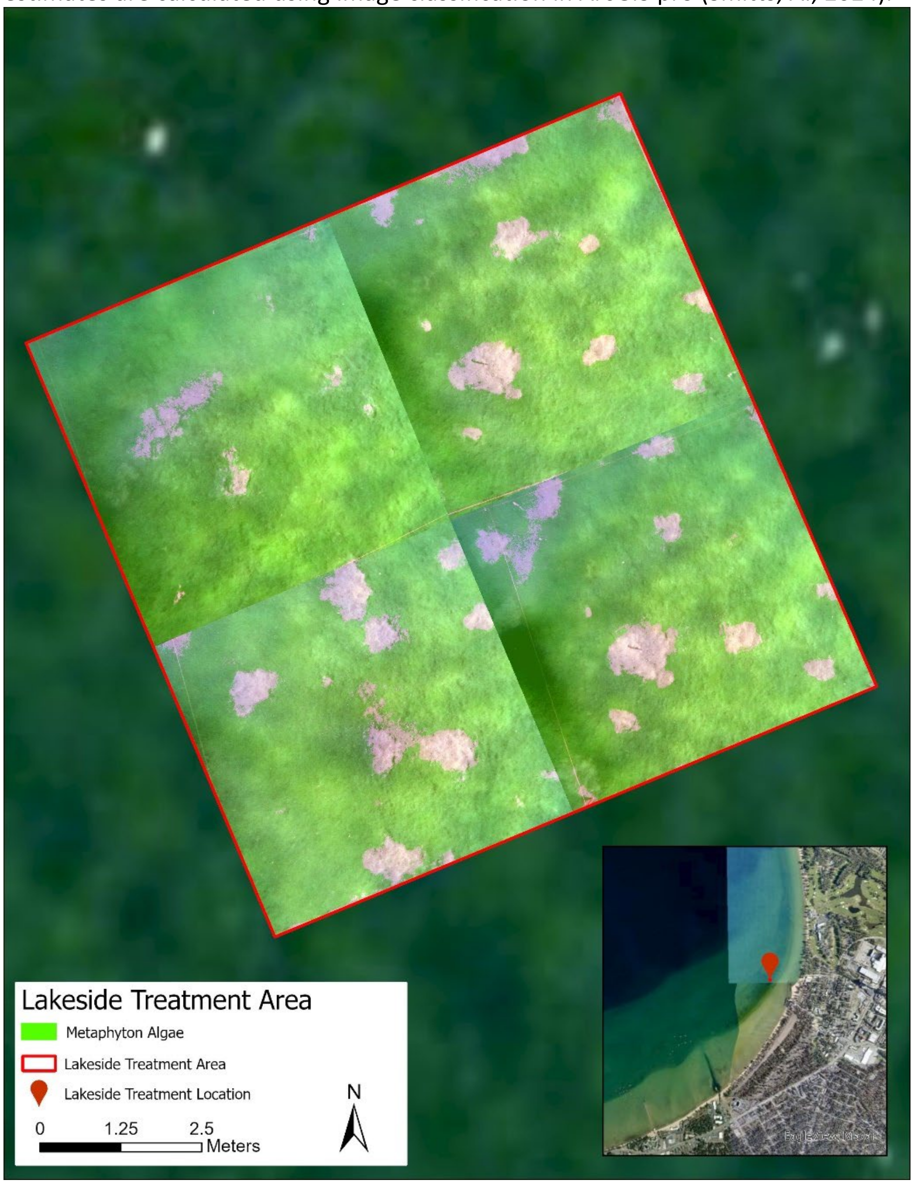

Figure 11: Lakeside treatment area showing metaphyton coverage in green.

Metaphyton removal using the developed technique was extremely successful at both sites. Nearly 100% of metaphyton algae was removed from the 10m x 10m area at the end of treatment. Table 1 outlines the metaphyton removal metrics for each site. Figure 12 shows a diver completing the remaining portion of the treatment area, demonstrating the effectiveness of the removal.

Metaphyton Removal Pilot Study								
Site	Date	Site Area (m^2)	Pre-Treatment		Post-Treatment		Elapsed Removal Time (min)	Removal Rate (m^2/hour)
			Metaphyton Coverage (%)	Metaphyton Area (m^2)	Metaphyton Coverage (%)	Metaphyton Area (m^2)		
Lakeside	9/18/2023	100	90	90	0	0	134	40
Whale Beach	9/19/2023	100	50	50	0	0	106	28

Table 1: Metaphyton removal metrics per treated site.

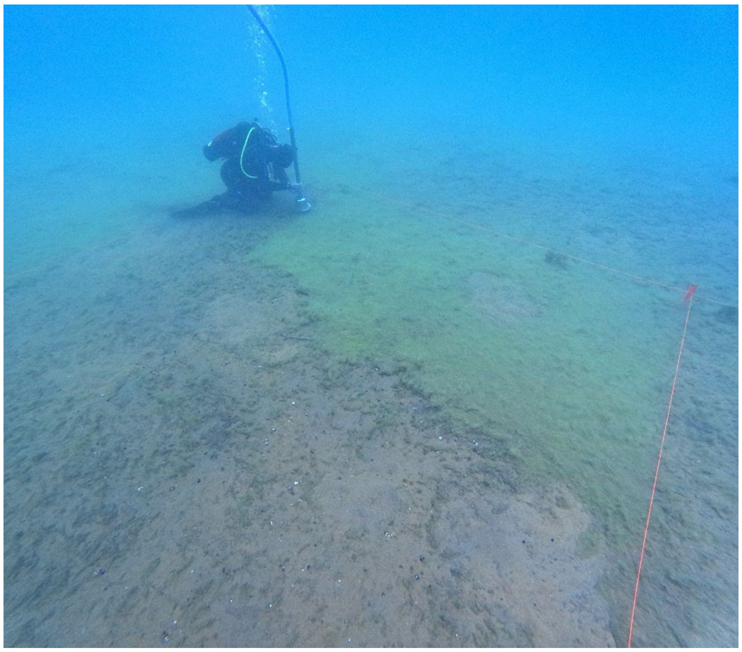

Figure 12: Diver completing metaphyton removal at Lakeside site.

As detailed in Table 1, the removal technique worked well in removing metaphyton from the designated area with no metaphyton remaining post-treatment. The average metaphyton removal rate between the two sites was 34m^2/hour. Metaphyton biomass removal estimates were calculated using samples taken adjacent to the removal site. It is estimated that 3599 g (7.9 lbs) were removed from Lakeside, and 281 g (0.6 lbs) were removed from Whale Beach (Table 2). Estimates on nutrients (carbon, nitrogen, phosphorous) removed from the lake through metaphyton removal were also completed (Table 3).

Metaphyton Removal							
Site	Date	Site Area (m^2)	Pre-Treatment	Post-Treatment	Metaphyton AFDM (g/m^2)	Metaphyton Biomass Removed (g)	Metaphyton Biomass Removed (lbs)
			Metaphyton Area (m^2)	Metaphyton Area (m^2)			
Lakeside	9/18/2023	100	90	0	40.0	3599.3	7.9
Whale Beach	9/19/2023	100	50	0	5.6	281.2	0.6

Table 2: Metaphyton removal biomass estimates per treated site.

Nutrient Removal						
Site	Date	Site Area (m^2)	Metaphyton Biomass Removed (g)	Carbon Removed (g)	Nitrogen Removed (g)	Phosphorous Removed (g)
Lakeside	9/18/2023	100	3599.3	2465.4	103.4	6.5
Whale Beach	9/19/2023	100	281.2	244.8	16.2	0.8

Table 3: Nutrient removal estimates per treated site.

In an effort to understand potential adverse effects on water clarity, turbidity measurements were measured during removal operations. Turbidity measurements were taken at the surface near the water effluent portion of the removal system were recorded consistently throughout the removal process. Generally, turbidity remained very low (<1 NTU) during metaphyton removal, well within Lake Tahoe objectives. However, there were times when turbidity data increased, reaching a maximum of 24 NTU. These increases in turbidity can be attributed to specific metaphyton and/or substrate characteristics of the area.

Hydrogen Peroxide clam control

The hydrogen peroxide (H_2O_2) control experiment aims to advance our overall knowledge of the behavior and mortality of AC, and to shed light on potential management tools and strategies. Behavioral observations were recorded as indicators of AC stress during the experimental exposure period. With the concept of using hydrogen peroxide exposure as a control technique, clam mortality is the desired behavioral outcome. Figure 13 displays data observed on AC behavior in 0ppm and 50ppm H_2O_2 concentrations. Behavioral data for all four H_2O_2 concentrations (0ppm, 0.005ppm, 0.5ppm, 50ppm) is available in Appendix 4.

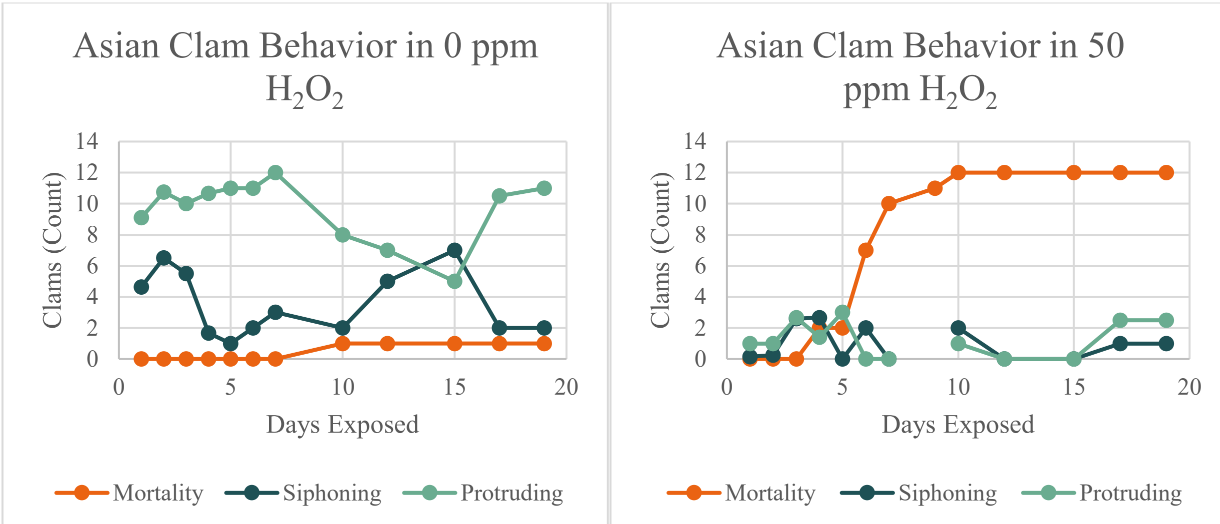

Figure 13: Asian clam behavior data for 0ppm and 50ppm H_2O_2 concentrations during the exposure period.

Asian clam mortality data from the experiment suggests that lower concentrations of H_2O_2 have minimal effects. The 50ppm concentration witnessed a significant increase in AC mortality when compared to the other weaker concentrations. The increase in mortality in the 50ppm could be attributed to the oxidative stress potential of hydrogen peroxide. At the end of the exposure period, the 50ppm contained 12 dead clams and 3 alive, an 80% mortality rate. Enacting a treatment method using 50ppm H_2O_2 could reduce AC populations but may not deliver total mortality in the treated population.

Discussion

Asian clam populations were detected at all five survey locations along the East shore of Lake Tahoe. Whale Beach and Chimney Beach contained well established AC populations with high enough densities to support metaphyton algae growth at both sites. Incline Beach, Hidden Beach, and Skunk Harbor contained AC populations in low numbers indicating that AC are in early stages of establishment at these sites. Currently, the AC numbers at Incline Beach, Hidden Beach, and Skunk Harbor are not large enough to support metaphyton growth. While these three sites do not currently have large clam populations, they do all contain suitable habitat (sand substrate) for the exponential growth of AC. Predicting the growth patterns of AC at each of these sites is challenging, but it is anticipated that populations will expand in future years. Using the Sand Harbor State Park AC population as a model, these populations can increase significantly in the first 3 – 4 years. It is hypothesized that populations at Incline Beach, Hidden Beach, and Skunk Harbor will be large enough to support metaphyton growth by 2027 if not sooner. Consequently, beaches at these locations may experience algae washing onshore with associated recreational impacts.

Metaphyton algae was detected at Whale Beach and Chimney Beach survey areas. Chimney Beach exhibited smaller amounts of metaphyton observed near dense populations of AC. Metaphyton was not prolific enough to be quantified through UAV imagery at Chimney Beach. Whale Beach contained significant amounts of metaphyton throughout the survey area, all coinciding with areas of dense populations of AC. Whale Beach contained AC densities of over 1000 clams/m^2. For perspective, the largest densities of AC in Lake Tahoe were recorded up to 8000 clams/m^2 (Wittman, 2012). Although densities at Whale Beach are high, there is room for the population to continue to grow, increasing negative impacts related to AC. The linkage between dense AC populations and substantial metaphyton growth continues to persist despite a reduction in metaphyton growth in the summer of 2023. As previously addressed, decreased metaphyton growth was observed throughout the entire nearshore of Lake Tahoe in 2023 (Smitts et al., 2024). It is expected that metaphyton algae will continue to proliferate at Whale

Beach and Chimney Beach locations while Incline Beach, Hidden Beach, and Skunk Harbor remain at risk to developing metaphyton.

The development of the diver assisted metaphyton removal technique was a novel approach to managing the negative effects of metaphyton algae, with the goal of removing algae before transport onshore. The pilot project, employing an in-situ 'vacuum' method of metaphyton removal from the bottom of the lake did prove effective. The system successfully removed all free floating metaphyton algae from the 10m x 10m survey area at both treatment locations. There are drawbacks to the pilot removal method with the main one being the heavy demand on resources. Diver assisted removal techniques require manual labor of dive teams to complete the treatment. From the pilot study, the average metaphyton removal rate was determined to be $34m^2$/hour or 0.0084 acres/hour. For context, the Whale Beach site had an estimated 6 acres of metaphyton coverage which translates to roughly 715 treatment hours to complete treatment of that area. These estimates indicate that the treatment method is not viable if implemented at its current scale. However, the feasibility of upscaling the vacuum metaphyton removal method should be assessed. With an increase in the vacuum surface area (from a small diameter hose, to a large swath) a larger area could be treated, increasing removal rates significantly. Successful upscaling of this method may permit the removal of metaphyton from a site like Whale Beach in one day. Another consideration when using the developed treatment method is turbidity side effects during the treatment process. While turbidity in the treatment area remained low for the majority of the time, there were spikes in turbidity that negatively impact Lake Tahoe's water clarity. If a similar system is implemented in the future, consistent turbidity monitoring should be recorded during operations. Ultimately, the diver assisted removal technique proved effective at removing metaphyton but would be time and cost prohibited on a large scale in its current state.

Controlling AC populations at specific Lake Tahoe locations has proved effective in prior treatment projects. Reducing AC densities through control methods mitigates the root problems related to AC, growth of metaphyton algae being a top priority. Bottom barrier treatment methods are an effective way of controlling populations but do require a significant investment. Exploring novel treatment methods provides alternative options to resource managers. The hydrogen peroxide treatment experiment completed with this project is an innovative method to managing AC populations. Experiment results provide important data related to clam mortality rates at various H_2O_2 concentrations. Clam mortality was achieved through sufficient H_2O_2 concentrations and exposure periods. The experiment was completed in a controlled laboratory representing Lake Tahoe conditions. Implementing a control method of this type in Lake Tahoe should be further researched as it presents challenges not addressed in the lab experiment. The continued development of novel and innovative control methods to combat AC at Lake Tahoe should be considered a priority for all stakeholders moving forward.

Recommendations

Asian clam populations at Lake Tahoe continue to spread throughout the lake. If left unrestricted, it is likely that AC populations will continue to proliferate throughout the nearshore of Lake Tahoe resulting in increased growth of metaphyton algae. As water temperatures continue to warm due to climate change, the reproductive season of AC will continue to increase, exacerbating the issue (Wittmann, 2012). Secondary effects, including the increase of metaphyton production in the nearshore, are expected to follow. The East shore of Lake Tahoe is especially susceptible to the growing AC population due to its suitable habitat and proximity to areas of previously established populations. In particular, popular East shore beaches and recreation areas are at high risk due to their sandy substrate and increased visitation. As AC populations continue to spread and grow in numbers, associated negative impacts are likely to increase at these beaches. The management of AC and their impacts to Lake Tahoe should continue at a localized level. The following resource management recommendations should be considered preliminary and should be followed up with additional data and discussion before implementation. Control strategies have benefits and drawbacks, and all consequences should be considered before implementing a specific strategy.

Public Outreach and Education

Eradication of AC from Lake Tahoe is not a realistic solution. However, reducing the spread of AC throughout the lake should be considered an important first line of defense. Watercraft remain a predominant vector for transport of AC to new areas in Lake Tahoe. Satellite populations of clams at beaches frequently visited by vessels continue to emerge. Data collected from this project corroborates this through Whale Beach and Chimney Beach sites. Resource managers around Lake Tahoe have previously dedicated resources to outreach programs aimed at reducing watercraft as a vector for aquatic invasive species (AIS). Outreach and education programs have been successful at spreading this message, and that should continue as applicable.

Key Management Items:

- Continued outreach and education programs geared towards minimizing the spread of AIS

As AC and metaphyton continue to expand to Tahoe's beaches, it is recommended that mitigation strategies be considered to combat adverse effects. Management strategies should be developed with the goal of preserving recreation and aesthetics at popular beaches. Management plans should be implemented on a site-by-site basis, targeting suitable control methods for individual locations. Strategies should target controlling the AC populations and/or associated metaphyton algae.

Treatment of high-density Asian clam population areas

When deemed necessary, the primary goal of AC treatment should be the establishment and retention of low AC densities through decided treatment method. As AC are difficult to eradicate and can recolonize efficiently, controlling AC populations to suppress metaphyton growth in targeted areas is a desired outcome. Targeting specific high-density areas may be the most efficient and cost-effective strategy to mitigate AC and associated impacts at Tahoe beaches. Bottom barrier control measures for AC have proven effective when implemented as treatment in Lake Tahoe (Berry 2022). Additionally, bottom barriers are considered to be the most effective and environmentally friendly option.

Key Management Items:

- Monitoring of Asian clam populations at predetermined locations/beaches
- Delineation of high-density Asian clam areas
- Implementation of proven treatment methods at designated areas

Development of alternative treatment methods for Asian clams

Alternative treatment methods for Asian clam removal should continue to be explored. Possible techniques include: suction removal, autonomous vehicles, volunteer divers. Diver assisted suction dredging has also been proven an effective control strategy (Wittman et al. 2012). A new approach to mitigating AC populations at Tahoe would be the enlistment of volunteer divers. Divers are capable of removing a significant amount of AC using limited tools such as a metal sieve. Partnering with local dive shops and organizations could provide opportunities for volunteer conservationists to have a positive impact on favorite Lake Tahoe beaches.

Key Management Items:

- Continued research and development of new treatment methods for controlling Asian clams
- Feasibility of volunteer diver removal method
- Develop removal rate (treated area/time) and cost estimates for various treatment methods
- Implementation of pilot treatment methods to test efficacy

Control strategies should also be developed to address metaphyton blooms. Controlling AC populations can be prohibitive for several reasons while managing metaphyton algae may prove a more manageable goal. As metaphyton is a relatively new challenge at Tahoe, various methods to manage algal mats and their impacts to shoreline should be explored. Metaphyton algae can wash onto beaches causing negative impacts to recreation and ecosystem health. The south shore of Lake Tahoe is a good example of the potential negative impacts of metaphyton algae (Figure 14).

Figure 14: Recreators wade through metaphyton algae at a beach in South Lake Tahoe.

Development of pre-transport treatment methods for metaphyton

Potential management actions to address metaphyton include removal of metaphyton algae pre or post transport onshore. Metaphyton control strategies for pre-transport entail underwater removal techniques which can add logistical complications. For example, the diver assisted removal method experimented in this project. The 'vacuum' method did prove effective, and the upscaling of the method may provide positive results. Alternatively, translating the vacuum method principles to use by autonomous vehicles has potential for an effective and viable removal strategy as well. The Tahoe Environmental Research Center is currently collaborating on pilot projects developing AUVs to remove metaphyton algae from the lake.

Key Management Items:

- Determine if metaphyton algae transport onshore is concern for site
- Develop pre-transport onshore removal techniques
- Implement management plan based on removal methods

Upscaling of pilot metaphyton removal method

The feasibility of upscaling the vacuum metaphyton removal method developed in this project should be further assessed. Increasing the vacuum surface area could increase removal rates significantly. Successful upscaling of this method may achieve desired metaphyton removal outcomes on a large scale.

Key Management Items:

- Determine optimal removal rate required for site(s)
- Determine feasibility of upscaling vacuum metaphyton removal method
- Develop prototype removal system
- Prototype tests at known metaphyton sites

Development of post-transport treatment methods for metaphyton

It may be determined that mitigating metaphyton impacts are more efficient after the metaphyton has been transported onshore. The severity of recreation and aesthetic impacts will vary on a site-by-site basis. Manual metaphyton removal from beaches may be a valid management practice. This could include human or mechanical solutions to assist in removal. Lake Tahoe is not the first place to explore algae removal from beaches and there are numerous solutions to beach cleanup approaches. The League to Save Lake Tahoe has tested innovative solutions for beach litter cleanups including robotic techniques (League to Save Lake Tahoe, BEBOT).

Key Management Items:

- Determine if metaphyton algae transport onshore is concern for site
- Develop post-transport onshore removal techniques
- Implement management plan based on removal methods

Exploring new and innovative solutions to successfully manage AC and metaphyton algae impacts at Lake Tahoe should follow an ongoing and iterative approach. Lake Tahoe is faced with continuously evolving environmental challenges due to many factors including invasive species such as the Asian clam. It is imperative that stakeholders continue to address these challenges in an effort to preserve the Lake Tahoe environment and its significant resources. TERC would like to thank the Nevada Division of State Lands for their continued partnership in the preservation of Lake Tahoe and its unique ecosystems through scientific knowledge.

Acknowledgements

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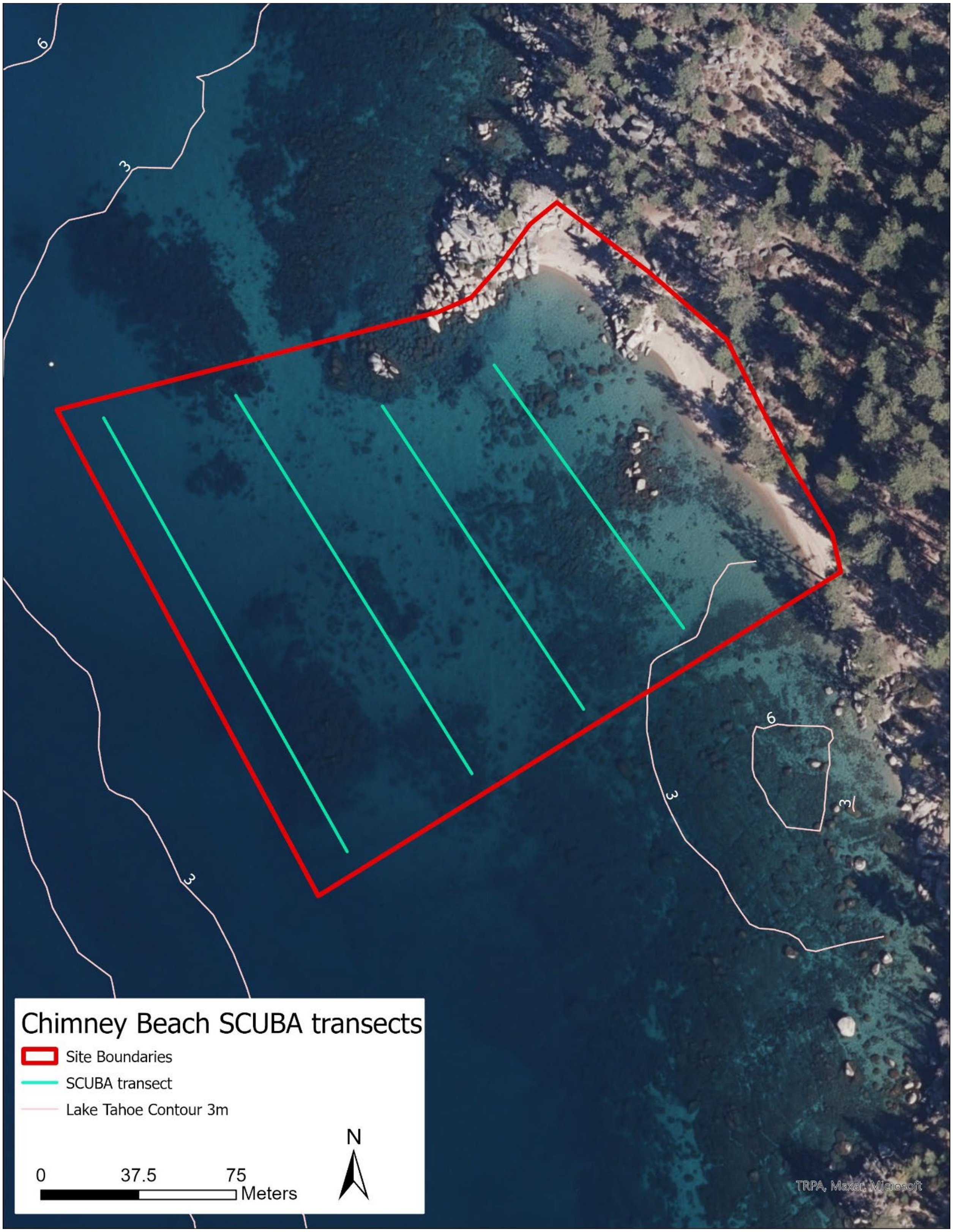
Leage to Save Lake Tahoe, BEBOT. https://www.keeptahoeblue.org/combat-pollution/beach-cleaning-robot/.

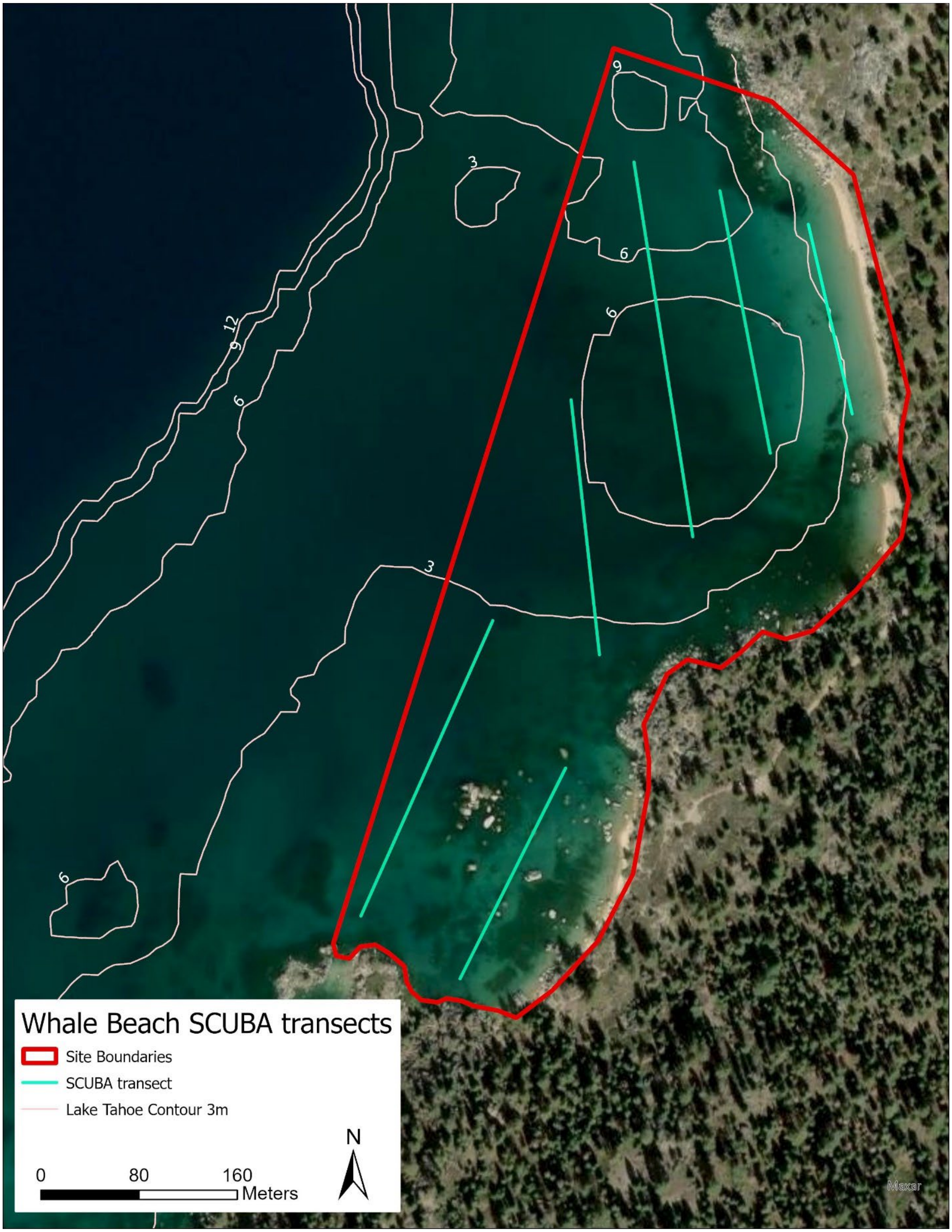
Appendix 1

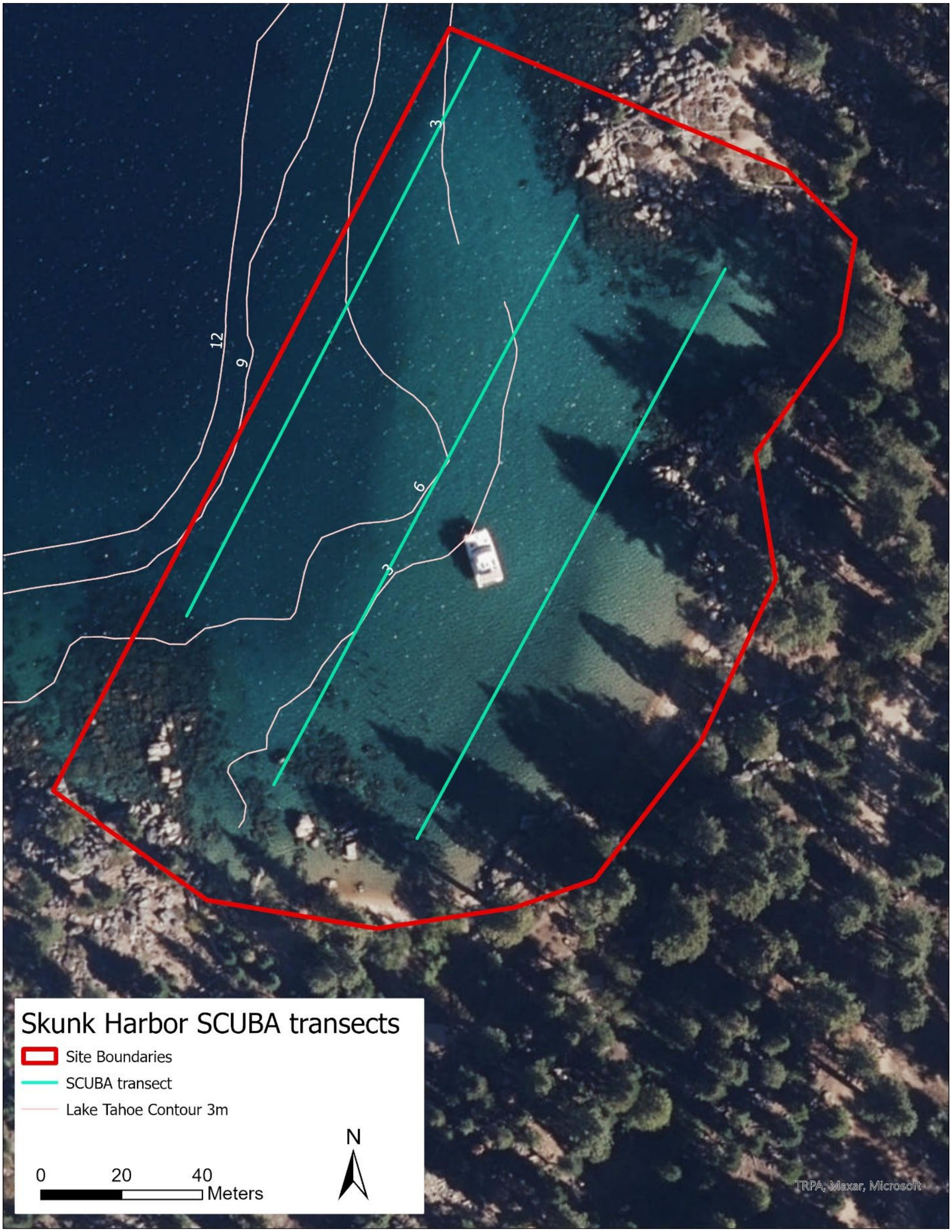
Site boundaries and SCUBA transect locations for each monitoring site.


Incline Beach SCUBA transects
Site Boundaries
SCUBA transect
Lake Tahoe Contour 3m
N
0
35
70
Meters
TRPA, Maxar, Microsoft
3
6
9
12


Hidden Beach SCUBA transects
Site Boundaries
SCUBA transect
Lake Tahoe Contour 3m
0
40
80
Meters
N
3
6
9
TRPA, Maxar, Microsoft

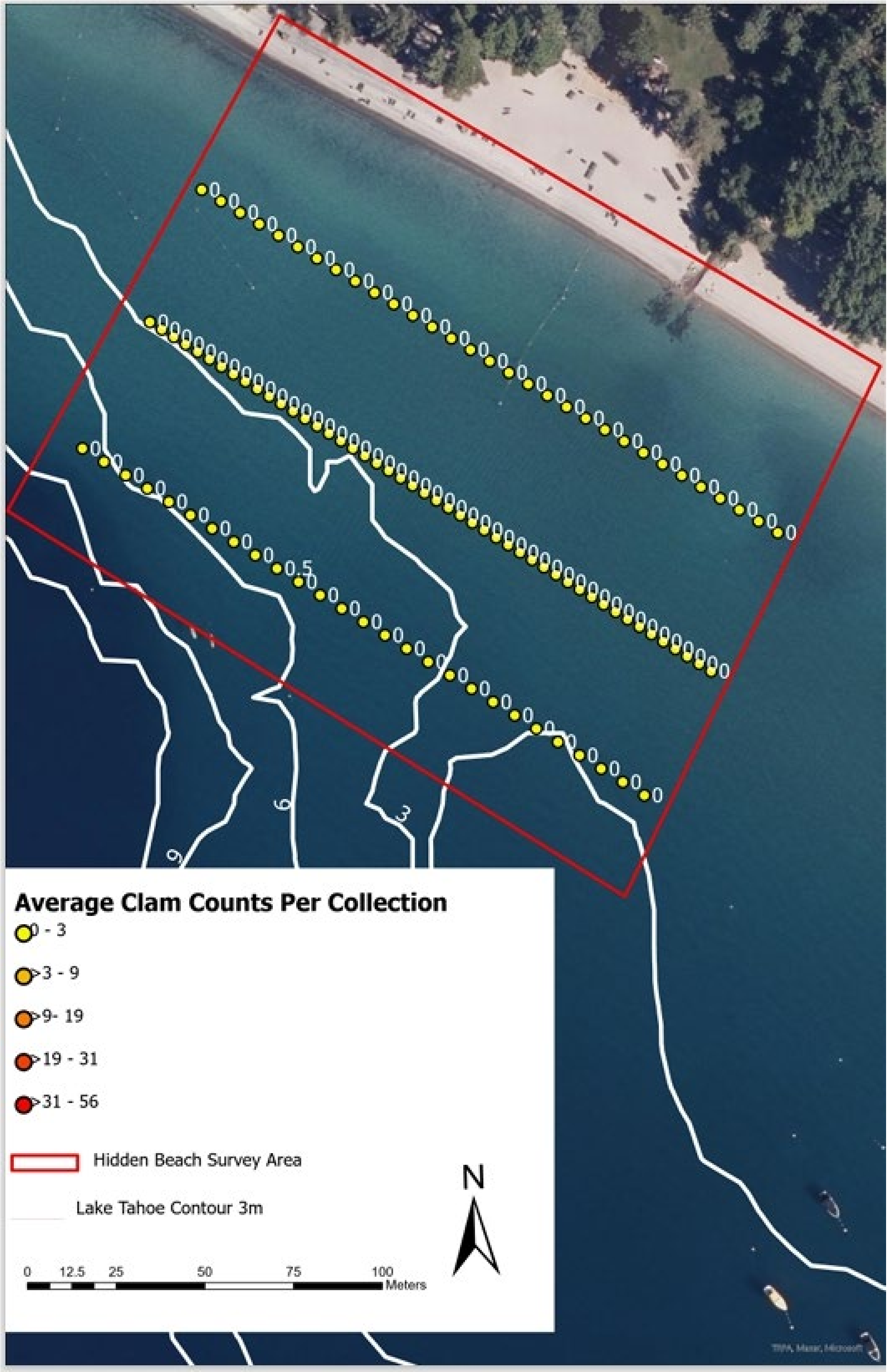

Chimney Beach SCUBA transects
Site Boundaries
SCUBA transect
Lake Tahoe Contour 3m
0
37.5
75
Meters
N
TRPA, Maxar, Microsoft
6
3
3
3
6
3


Whale Beach SCUBA transects
Site Boundaries
SCUBA transect
Lake Tahoe Contour 3m
N
0
80
160
Meters
3
6
9
12
Maxar

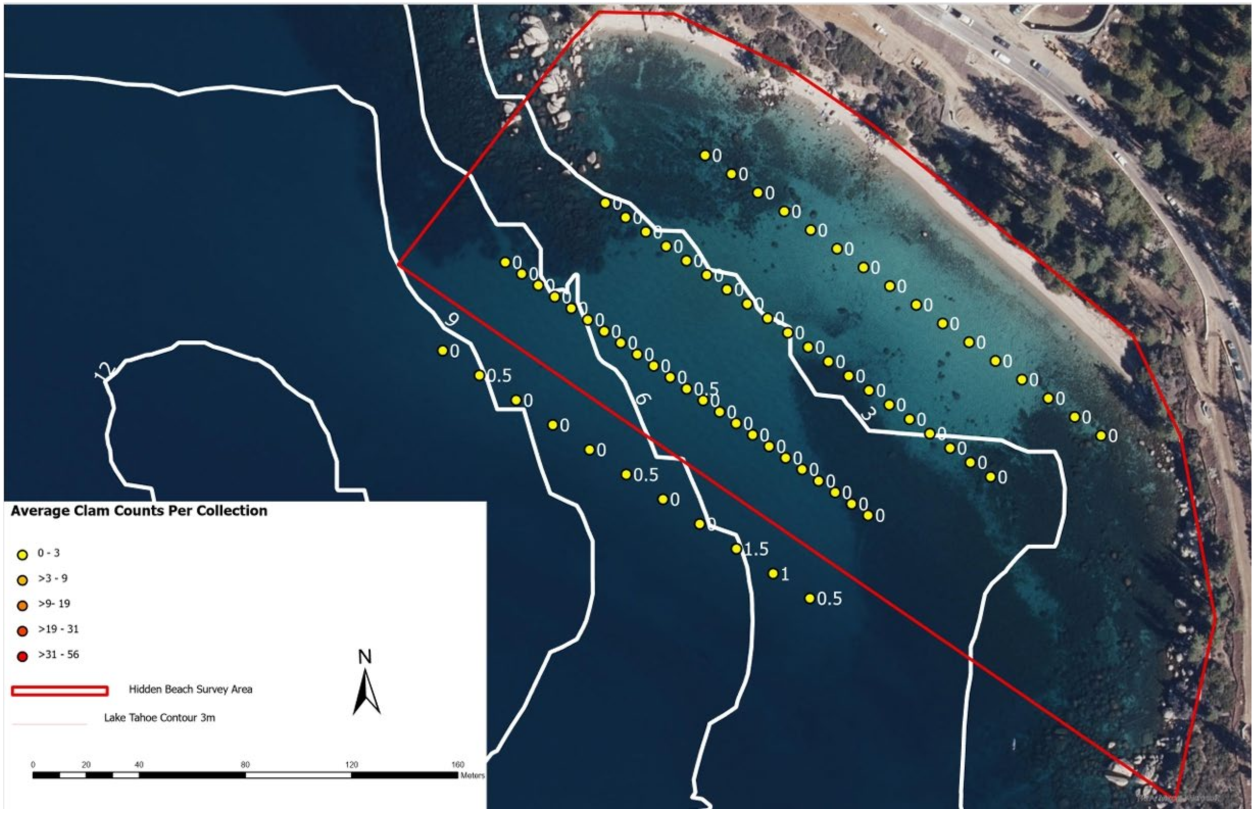

Skunk Harbor SCUBA transects
Site Boundaries
SCUBA transect
Lake Tahoe Contour 3m
N
0
20
40
Meters
TRPA, Maxar, Microsoft
3
12
9
6
3

Appendix 2

Average number of clams collected per scoop at Incline Beach survey area

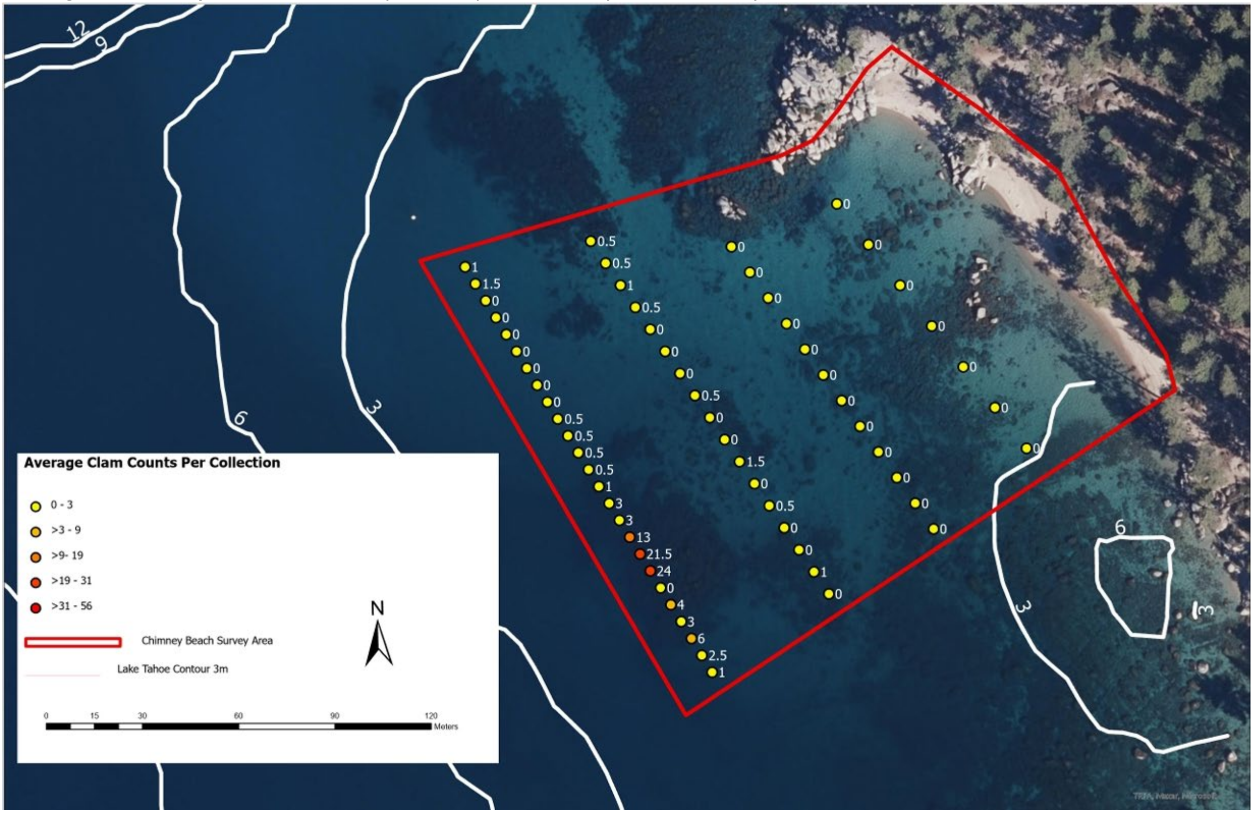


Average number of clams collected per scoop at Hidden Beach survey area

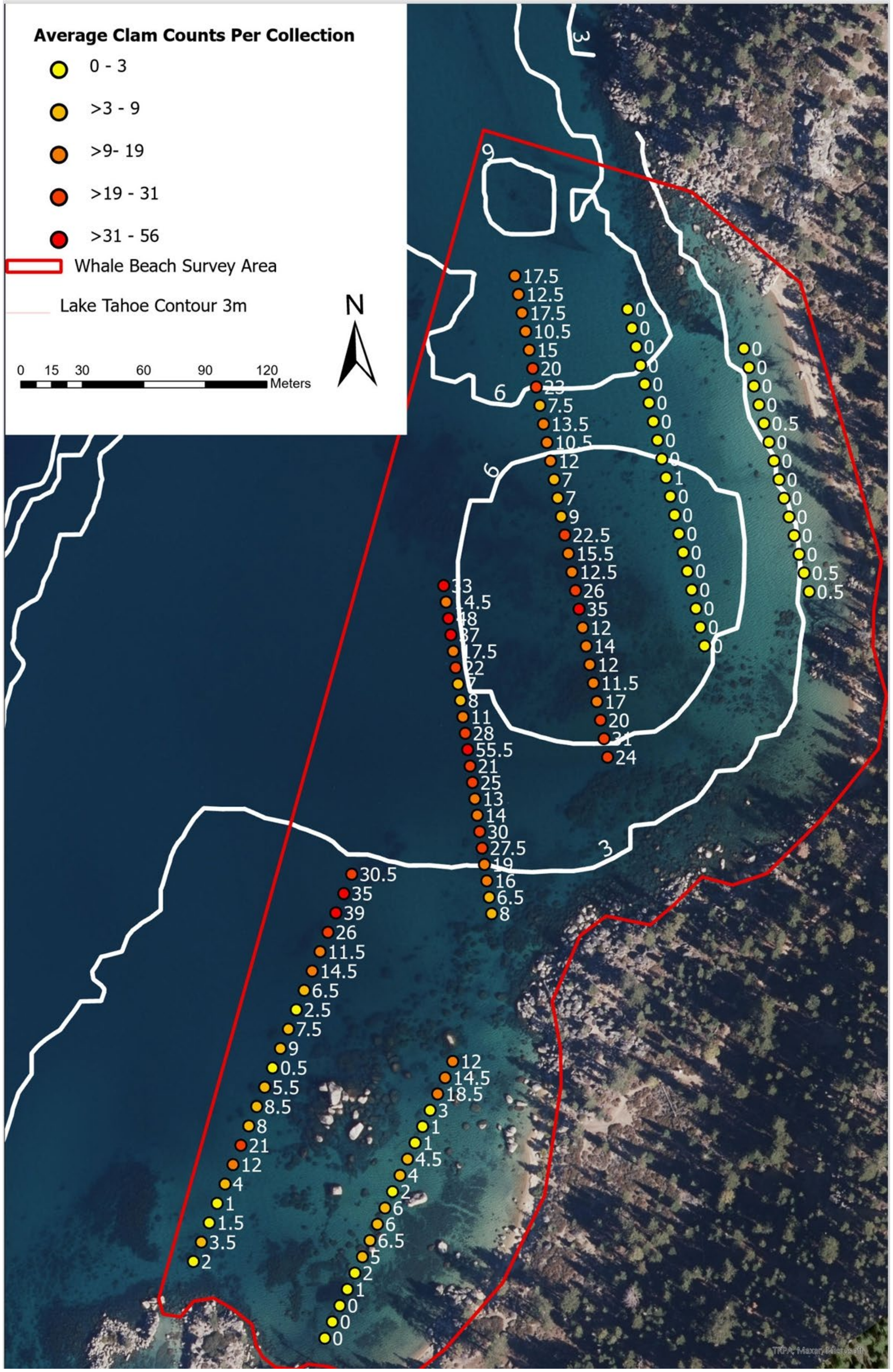


Average Clam Counts Per Collection
0 - 3
>3 - 9
>9- 19
>19 - 31
>31 - 56
Hidden Beach Survey Area
Lake Tahoe Contour 3m
N
0
20
40
80
120
160
Meters

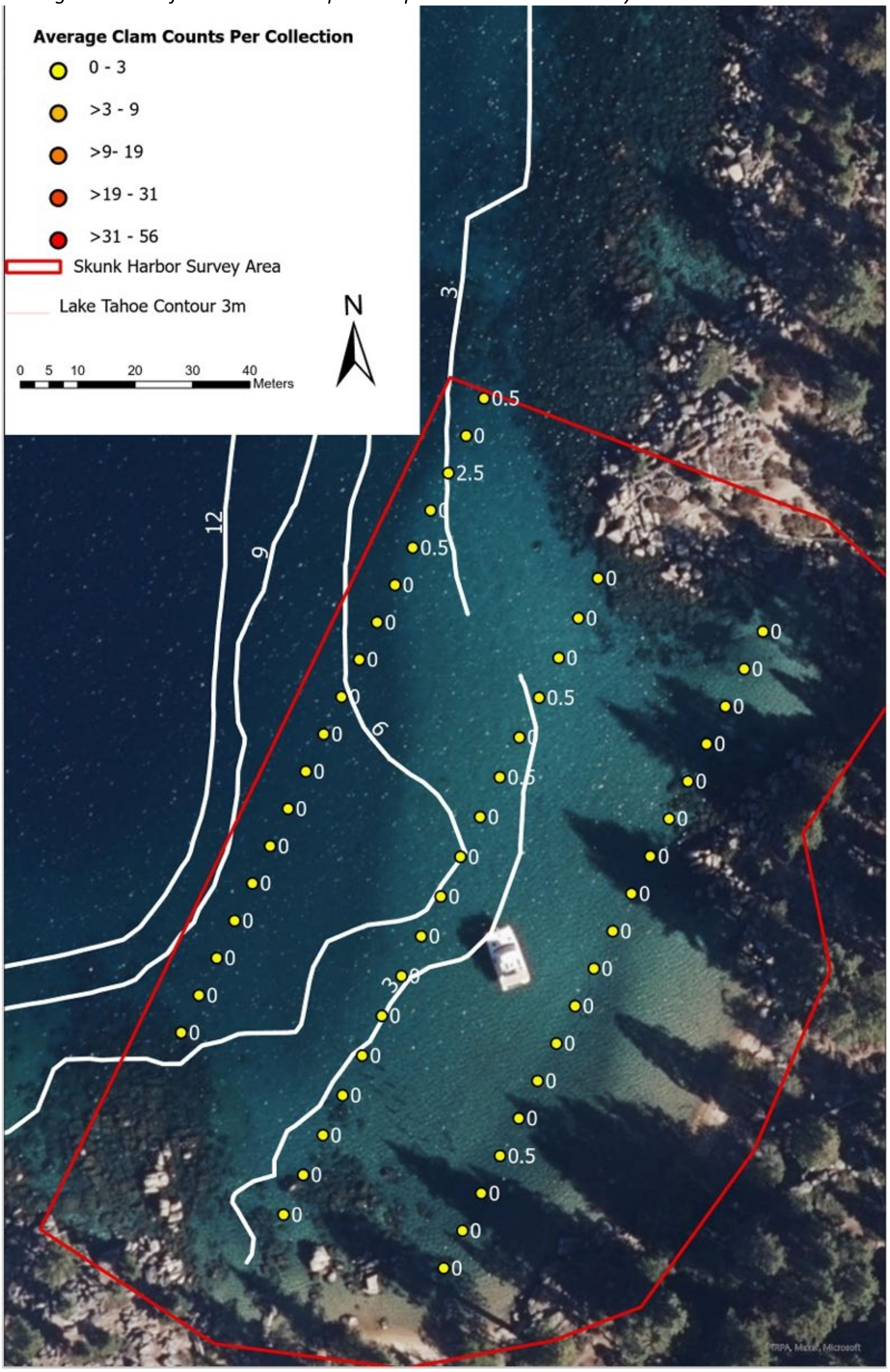
Average number of clams collected per scoop at Chimney Beach survey area



Average number of clams collected per scoop at Whale Beach survey area

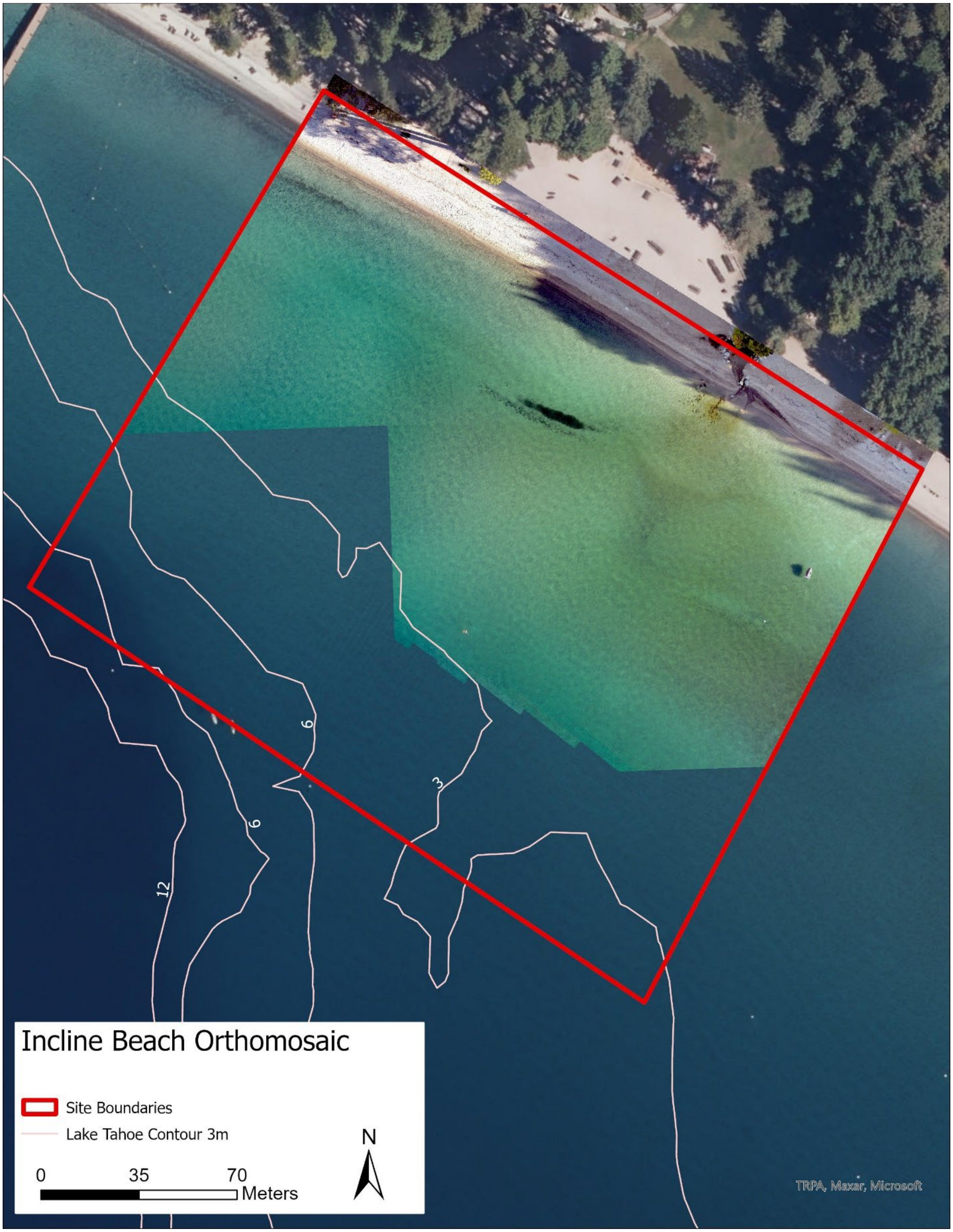


Average number of clams collected per scoop at Skunk Harbor survey area

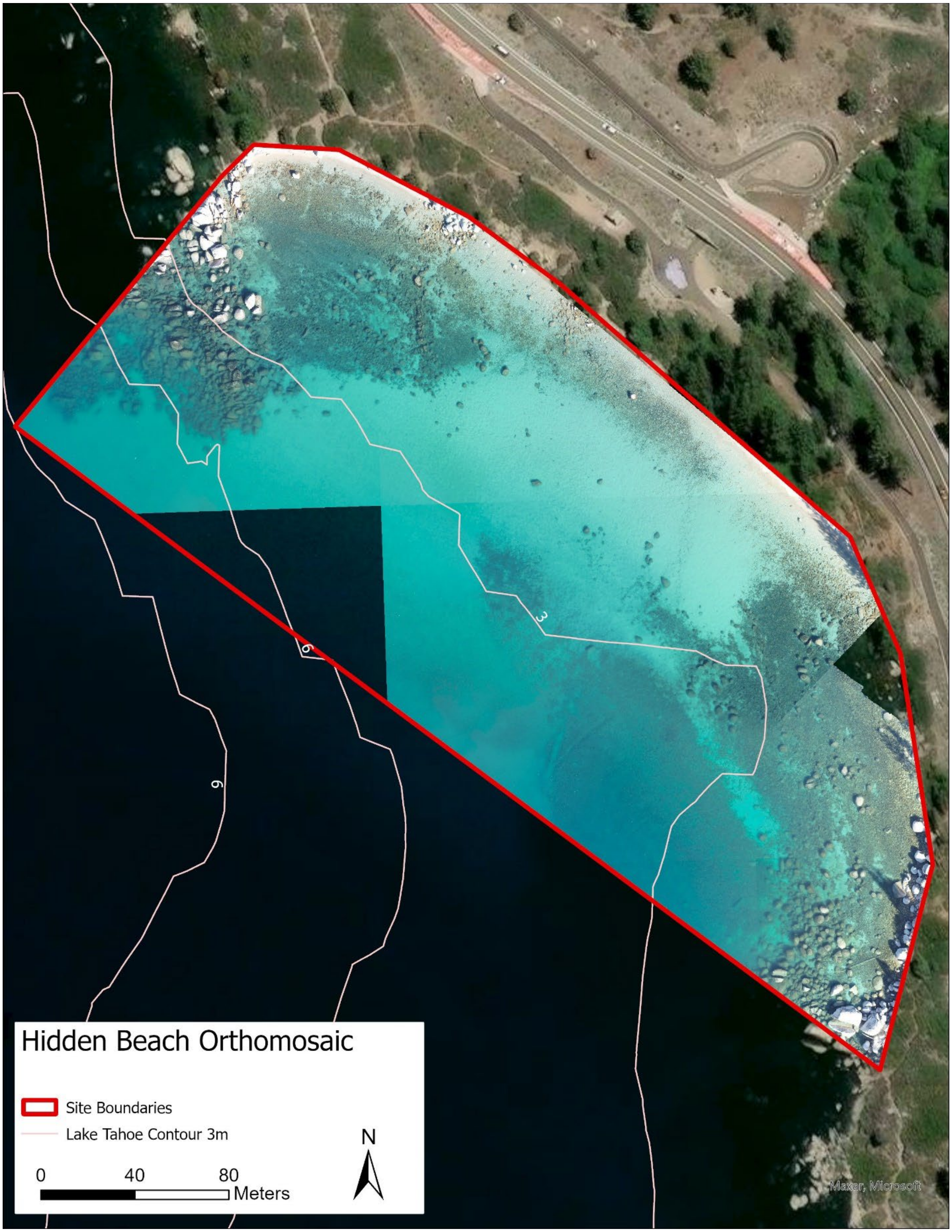


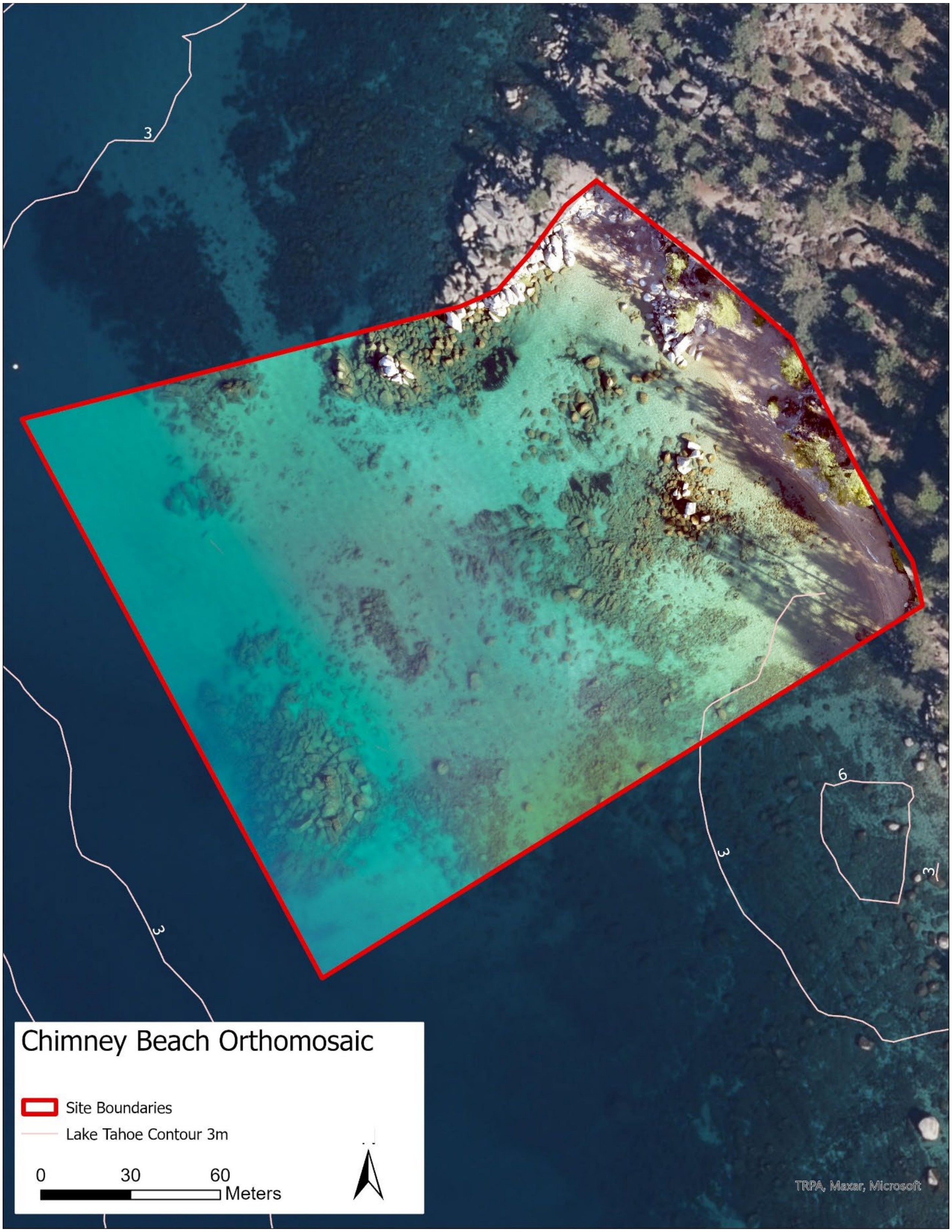
Appendix 3

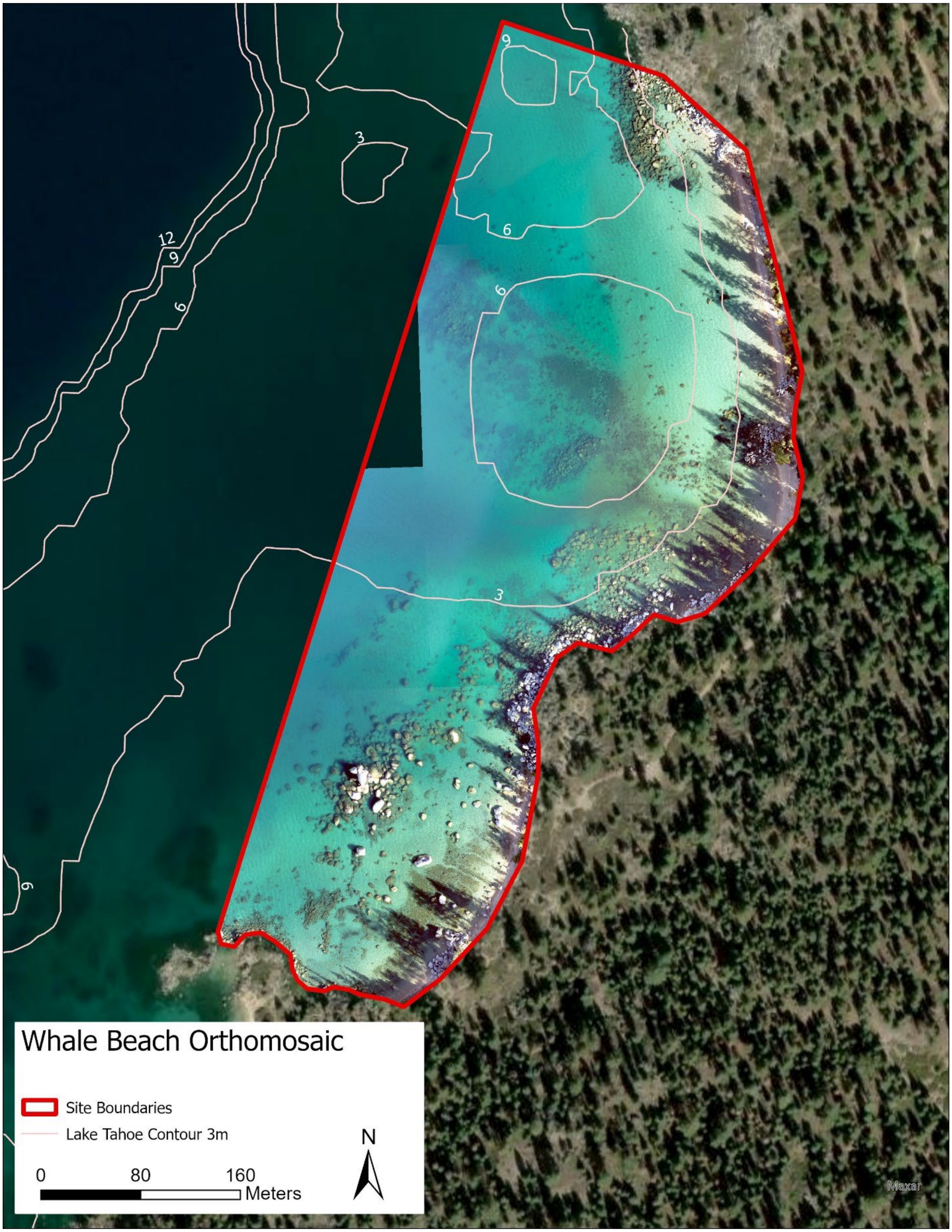
Orthomosaic imagery data for each monitoring site.



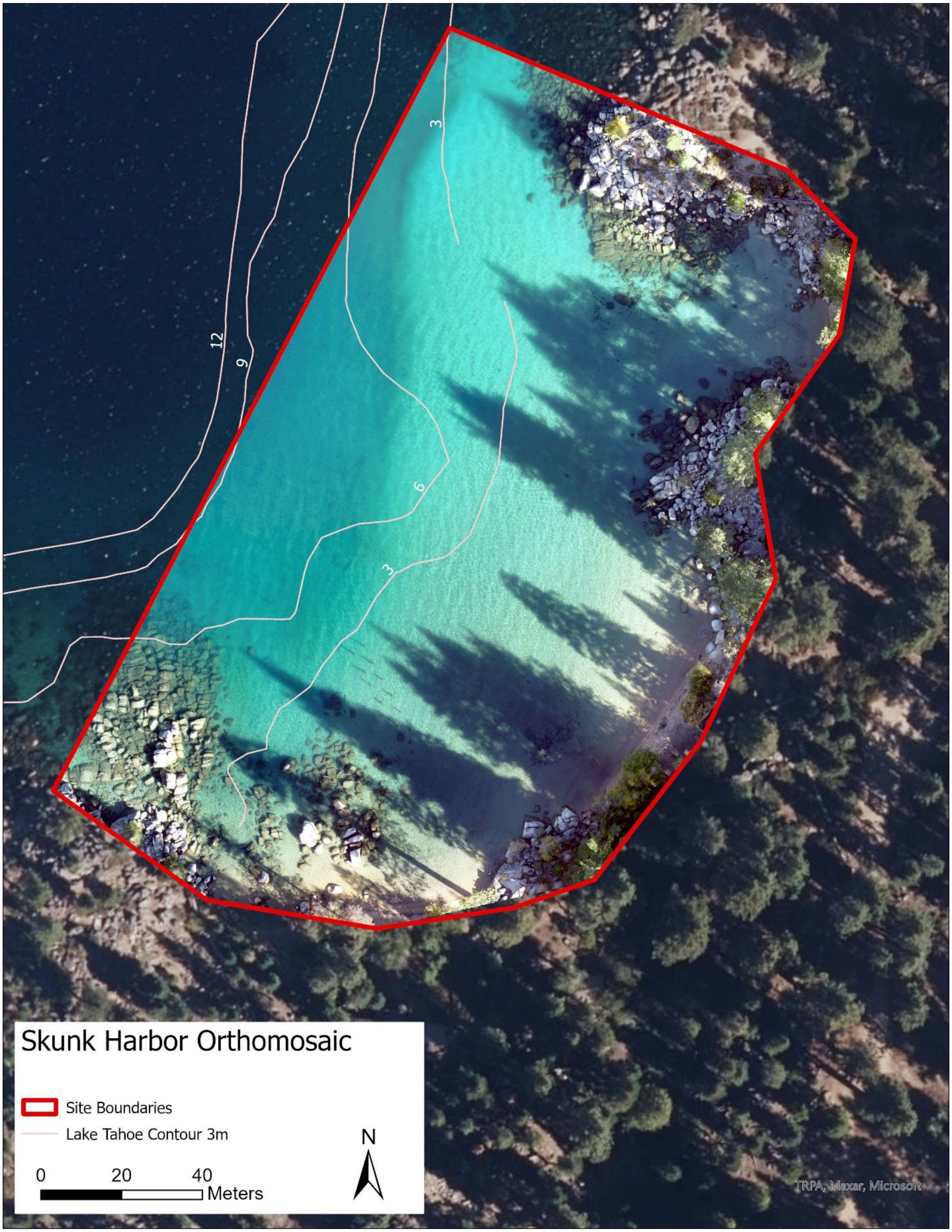
Incline Beach Orthomosaic
Site Boundaries
Lake Tahoe Contour 3m
0
35
70
Meters
N
TRPA, Maxar, Microsoft
3
6
6
12


Hidden Beach Orthomosaic
Site Boundaries
Lake Tahoe Contour 3m
0
40
80
Meters
N
3
6
9
Maxar, Microsoft


Chimney Beach Orthomosaic
Site Boundaries
Lake Tahoe Contour 3m
0
30
60
Meters
3
3
3
3
6
TRPA, Maxar, Microsoft

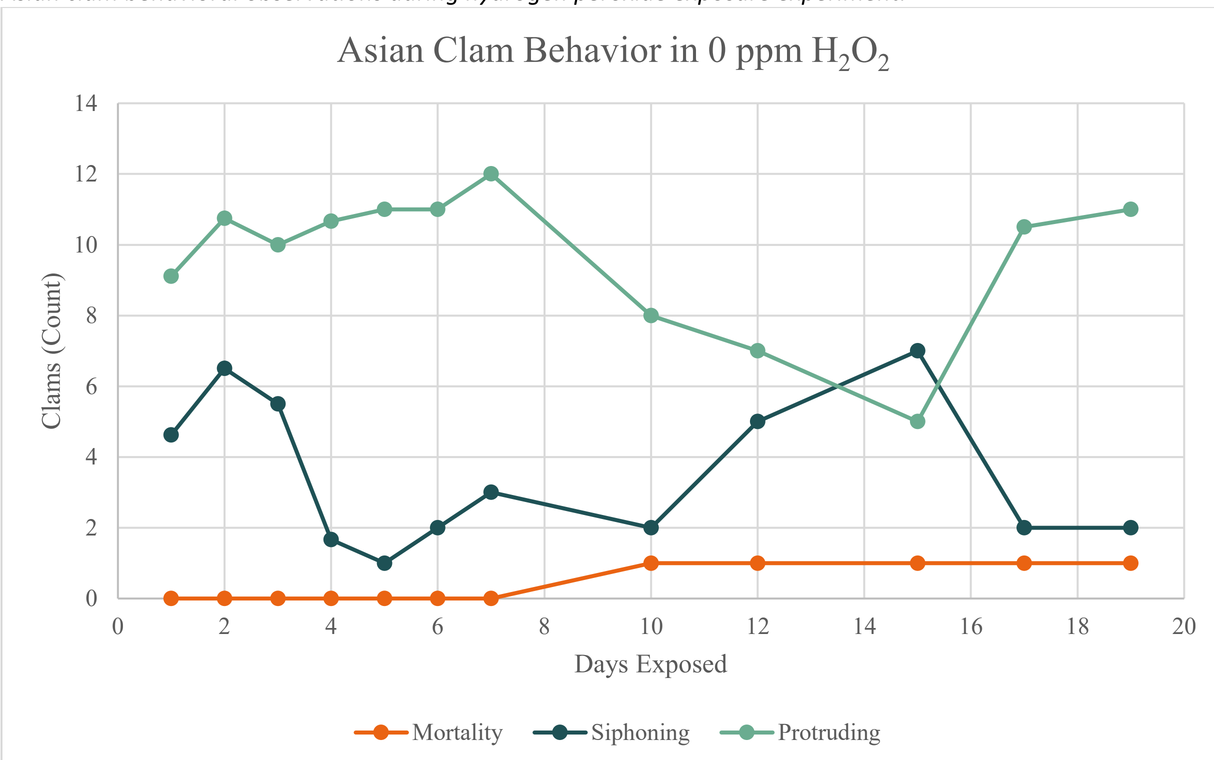


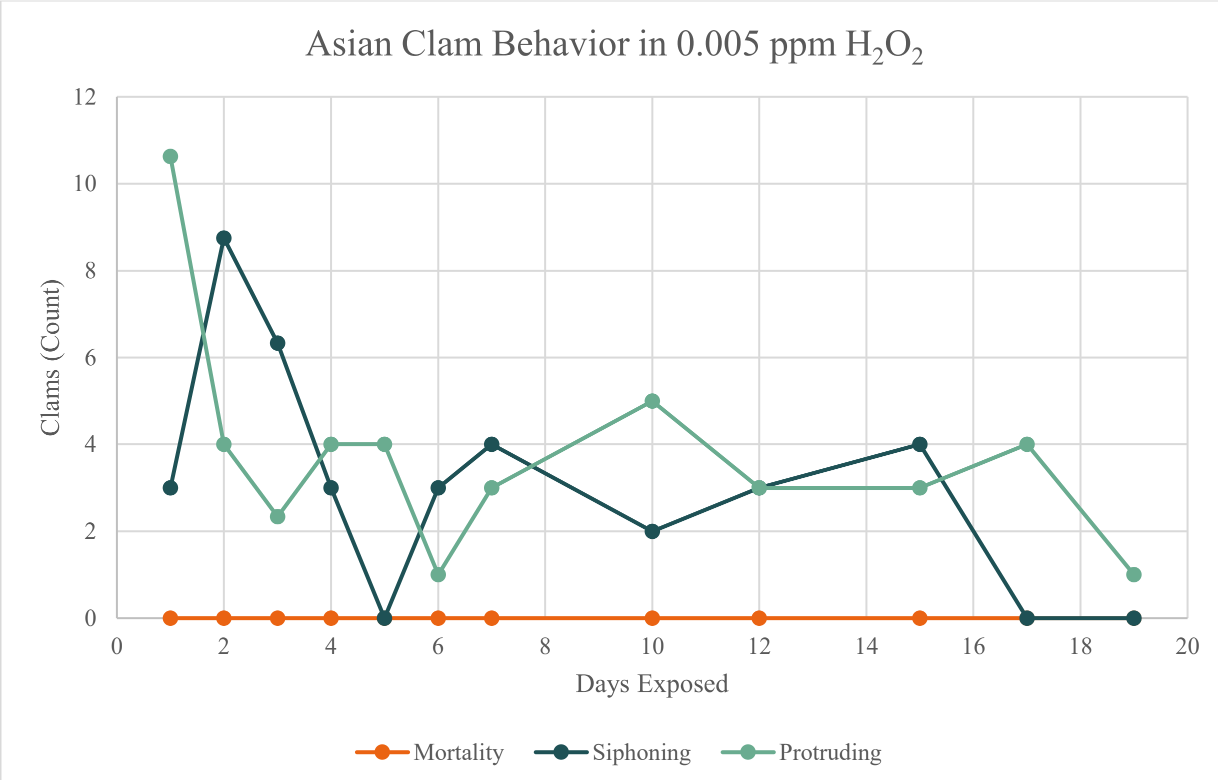
Whale Beach Orthomosaic
Site Boundaries
Lake Tahoe Contour 3m
0
80
160
Meters
N
3
6
9
12
Maxar

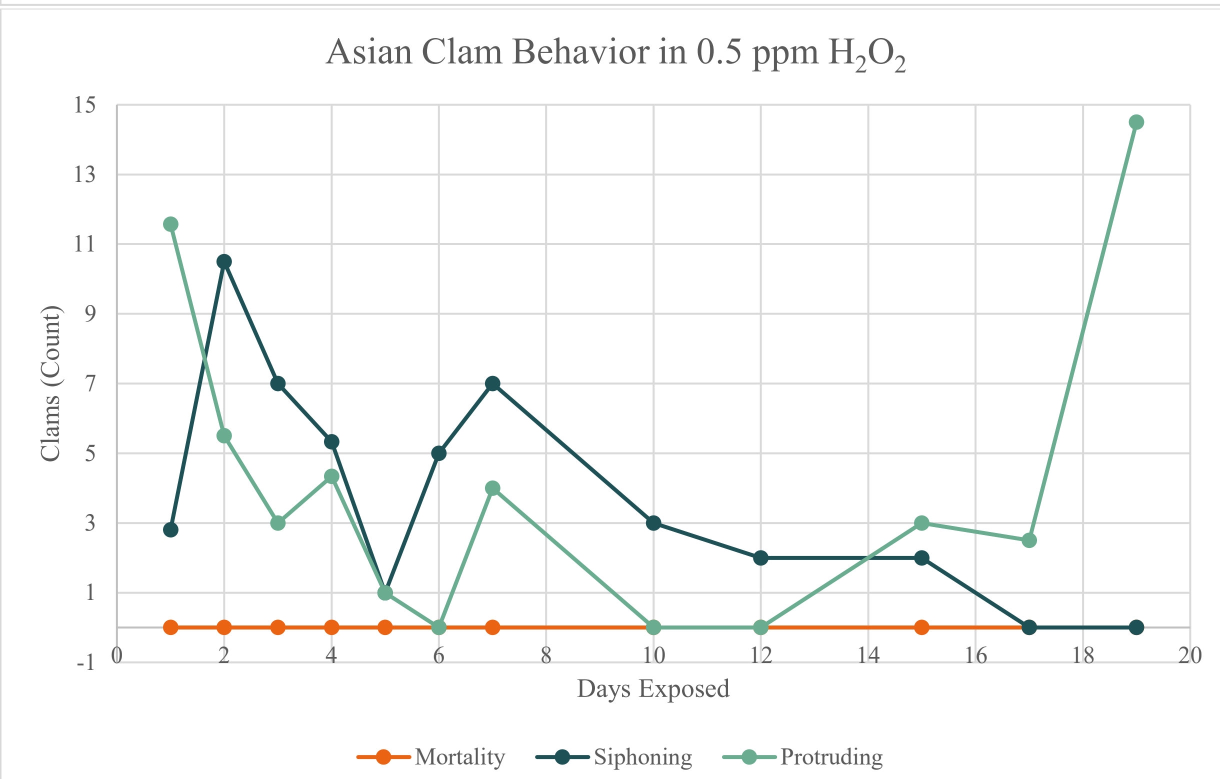

Skunk Harbor Orthomosaic
Site Boundaries
Lake Tahoe Contour 3m
0
20
40
Meters
N
TRPA, Maxar, Microsoft
3
12
9
6
3

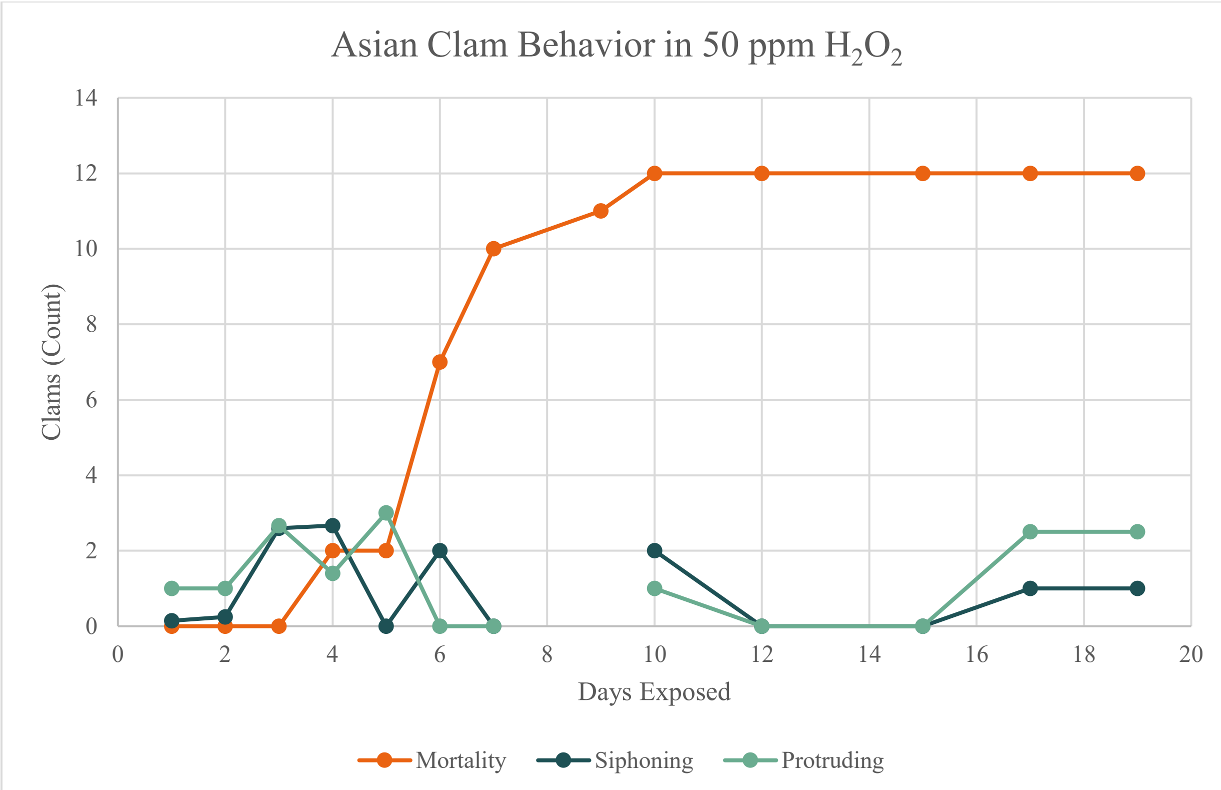
Appendix 4

Asian clam behavioral observations during hydrogen peroxide exposure experiment.




Asian Clam Behavior in 0.005 ppm H_2O_2
Clams (Count)
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
Days Exposed
Mortality
Siphoning
Protruding


Asian Clam Behavior in 0.5 ppm H_2O_2
Clams (Count)
15
13
11
9
7
5
3
1
-1
0
2
4
6
8
10
12
14
16
18
20
Days Exposed
Mortality
Siphoning
Protruding



Asian Clam Behavior in 50 ppm H_2O_2
Clams (Count)
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
Days Exposed
Mortality
Siphoning
Protruding

Appendix 5

Link to Lake Tahoe East shore Asian clam population web map.
https://experience.arcgis.com/experience/94964cc64c3d42a0957e356c04af8922