Utah Lake Marina HAB Treatments

Evaluation of Treatment Effectiveness

2021 Interim Report

EXECUTIVE SUMMARY

Algaecides were applied approximately weekly to all of Utah Lake's public marinas in the latter part of the 2021 recreation season. These treatments were broadly effective at minimizing risks of recreationists' exposure to toxigenic cyanobacteria within the treatment areas. As noted in preliminary trials in 2020, the control of Harmful Algal Blooms (HABs) using algaecides is resource intensive. Positive treatment outcomes were often short-lived, likely due to recolonization from cyanobacteria in the open waters of Utah Lake. Also, the efficacy of treatments was variable through time and across different marinas. Copper concentration increased considerably in the day following treatments, but returned to concentrations that were not a threat to aquatic life within a week. Algaecide treatments may continue to be an important tool in reducing the magnitude and intensity of HABs in the marinas of Utah Lake as part of comprehensive, adaptive management remediation efforts, but several recommendations should be considered if these strategies are continued.

Utah Division of Water Quality

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Additional Resources

EutroPHIX Interim Treatment Report

https://drive.google.com/file/d/1vO24iQwobp9KIXQyleiGDVWFXmEoe2p9/view?usp=sharing

DWQ Monitoring Sample and Analysis Plan
https://docs.google.com/document/d/1c56OJDNXAAj5TbTEl1Xi8Nch3PsZZEMk/edit?usp=sharing&ouid=112667072061926237928&rtpof=true&sd=true

Utah Lake Water Quality Study
https://deq.utah.gov/water-quality/utah-lake-water-quality-study

Harmful Algal Blooms
https://deq.utah.gov/water-quality/harmful-algal-blooms-home

Key Findings and Recommendations

- Almost all of the HAB treatments (25/29) that were conducted in 2021 were successful in reducing toxigenic cyanobacteria. However, only 34% of treatments were successful at reducing cell densities below the health advisory threshold of 100,000 cells/mL; and the densities returned to pretreatment levels sometimes exceeding pretreatment densities within a week of applications. Recommendations include:
    - Treatments should occur earlier in the season to prevent densities from reaching these levels;
    - Consider installation of additional bubble curtains or otherwise reconfiguring marina entrances to reduce intrusions of HAB taxa into the marinas from the open waters of Utah Lake.
- Treatments in two marinas demonstrated exceedances of the chronic copper criterion one day after treatment and after 7 days remained slightly higher than pre-treatment levels. Recommendations include:
    - Future treatments using copper compounds should be carefully applied and monitored to ensure that copper does not accumulate to levels that threaten aquatic life.
    - Consider using peroxide treatments more frequently, especially if copper accumulations are observed in the marinas.
- Since algaecides may affect cyanobacteria species composition and subsequently cyanotoxin production, it is important to continue to conduct composition monitoring during future treatment projects.
- Maintain the strong collaboration established among treatment contractors and Utah's Divisions of Forestry, Fire, and State Lands, State Parks and Recreation, and DWQ to ensure that the treatments are implemented quickly and efficiently.
    - Jointly develop a comprehensive treatment and monitoring strategy for Utah Lake which will be critical to applying treatments and preventative strategies,
    - Identify and secure long-term funding to allow treatments to be planned early in the year and applied earlier in the season.
- Continue to treat marinas to minimize threats to recreational uses over the short term, but:

- Consider whether expanded treatments to include cyanobacterial sources of origin (hotspot treatment) or larger portions of the lake should be incorporated into longer-term remediation efforts for Utah Lake.

INTRODUCTION

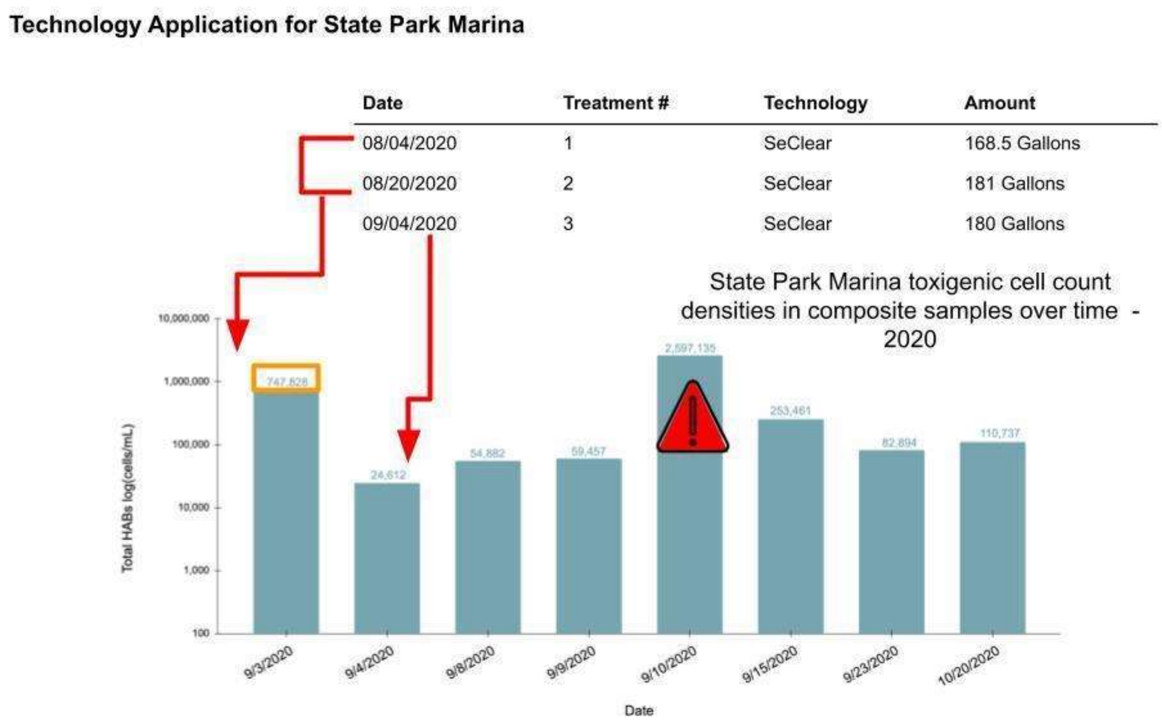
Utah Lake has a long history of extensive and sometimes toxic blooms of toxigenic cyanobacteria, commonly called Harmful Algal Blooms (HABs). The lake is currently listed by the Division of Water Quality (DWQ) as failing to meet its recreational uses due to this water quality problem. HABs occur when certain cyanobacteria, a type of phytoplankton, become abundant enough to change the visual and physical nature of the waterbody. A HAB is defined as an aggregation or accumulation of either toxic or non-toxic cyanobacteria that poses a reasonable exposure risk to the public. This report focuses on the density of toxigenic cyanobacteria, which are cyanobacteria that are known to produce cyanotoxins under the right conditions. Although technically cyanobacterial blooms, most water protection agencies have adopted the term “harmful algal blooms” to describe these events, and for consistency, DWQ uses the same terminology.

The number and intensity (i.e., magnitude, frequency, or extent) of HABs has been increasing worldwide due to ongoing human-caused nutrient enrichment, higher water temperatures from global climate change. Both of these root causes of HABs are costly and time consuming to address. DWQ is actively working to develop nutrient reduction strategies for Utah Lake in partnership with local entities and other state and federal agencies (see Utah Lake Water Quality Study). Further, the Division of Water Quality has implemented a robust public health advisory program in partnership with local health departments and the State Department of Health (see habs.utah.gov). In addition, several complementary management strategies have been evaluated to mitigate the harm caused by HABs to improve access to safe water-based recreation in Utah Lake while longer-term solutions are being implemented. These management strategies include mechanical, chemical/physical, and biological control mechanisms. While each has been demonstrated to achieve the objective of reducing the intensity of blooms, effectiveness can vary based on waterbody conditions or application methods. Particularly in larger lakes, like Utah Lake, treatments can be costly with improvements that are short-lived. As a result, it is critical to better understand circumstances where various treatments are most likely to achieve management objectives. Therefore, marinas were targeted for treatments in order to maximize the likelihood of improving recreational use opportunities on Utah Lake.

It is also possible that some algae treatments could cause unintended consequences. For example, large and rapid reductions in phytoplankton biomass could potentially generate large quantities of labile carbon, which could increase ecosystem respiration rates and cause a depletion of dissolved oxygen. High levels of cyanotoxins could be released if cyanobacteria cells are lysed due to a treatment. Treatments may promote a resource vacuum that is populated with more noxious cyanobacteria. Finally, some chemical treatments are potentially toxic to desirable lake biota; not only in the short-term exposure, but residual chemicals accumulate in successive treatments in the lake sediment. For these reasons it is important to determine the conditions where such unintended consequences occur for different treatment options.

In 2020, several HAB treatments were conducted on Utah Lake; most were successful in reducing cyanobacteria cell counts, at least over short time scales (Figure 1). Following these treatment pilot studies, in 2021, the Utah Lake Legislature allocated ~$1M to the Division of Forestry, Fire, and State Lands (FFSL), of this $594K was earmarked to directly support HAB treatments in each of Utah Lake's publicly-accessible marina harbors, with the additional goal to propose methods to minimize water exchange between the open waters of Utah Lake and the marinas. Utah's DWQ partnered with FFSL to solicit proposals from companies to conduct the treatments and for DWQ to conduct independent monitoring of treatment effectiveness at mitigating adverse impacts to recreation use caused by HABs.

Figure 1. Demonstration of short-term reductions in HABs following 2020 treatments. The red triangle indicates an exceedance of the 100,000 cells/mL health advisory threshold.



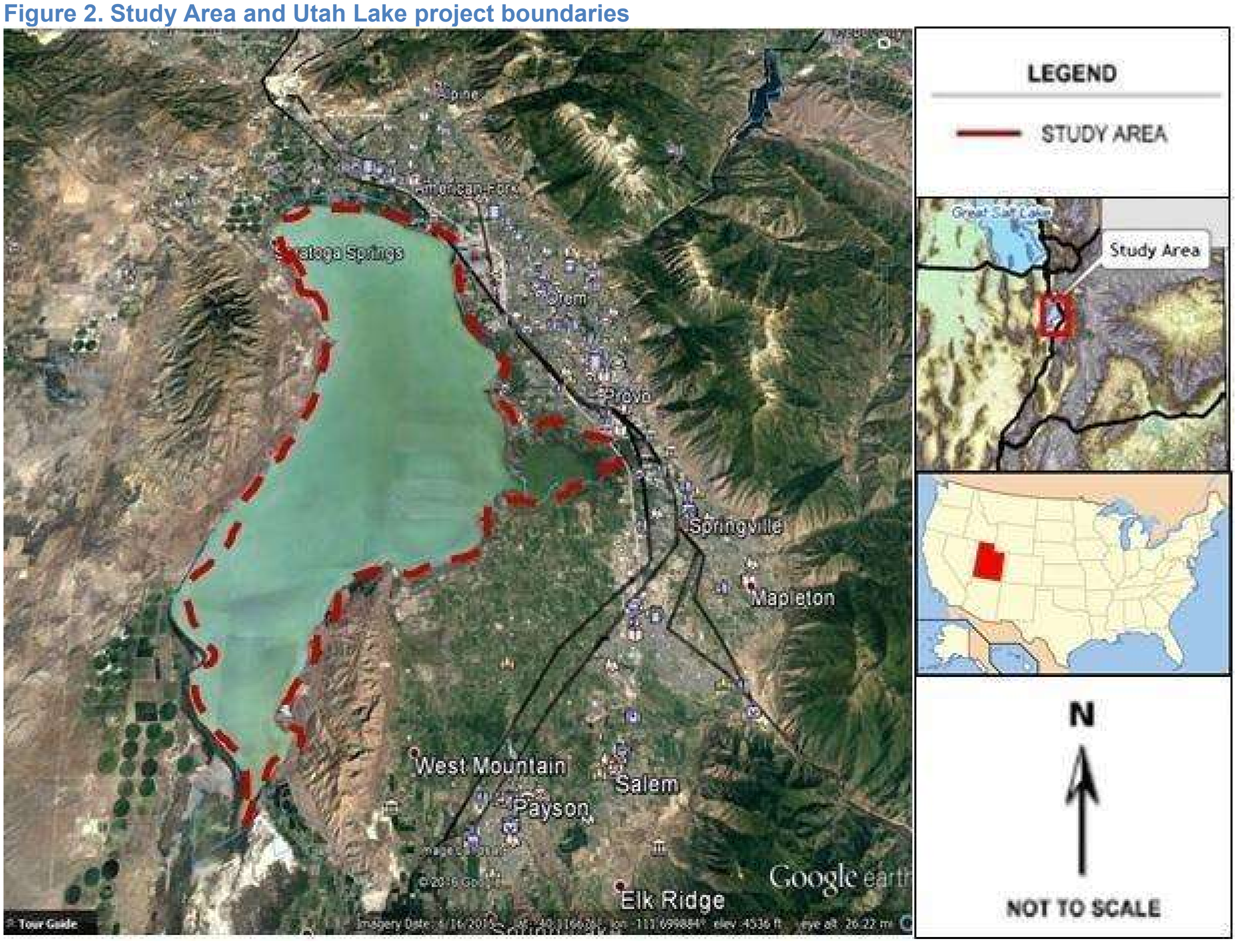
Several proposals were submitted and the review panel ultimately selected EutroPHIX, a national company that specializes in HAB treatments, to conduct the work. The contract was in place as early in the fiscal year as possible and treatments were initiated starting in early August and continued into October. This interim report provides information on what was learned in this process and makes recommendations for any future treatments that occur on Utah Lake. Work is anticipated to continue into 2022 and a final report and recommendations will be completed at the end of the project.

STUDY AREA

Utah Lake is a remnant of Lake Bonneville located within Utah Valley and surrounded by the Provo-Orem metropolitan area (Figure 2). Utah Lake is a valuable ecological and recreational resource in Utah Valley and its beneficial uses are summarized in Table 1. The lake is about 40 km long and 12 km wide and has a drainage area of about 7,500 square kilometers. The lake can be described as a shallow, turbid, slightly-saline, eutrophic lake in a semi-arid region. It has one river outlet, the Jordan River, which is a tributary of the Great Salt Lake. The maximum lake elevation is 4,489 feet above sea level which is referred to as the “compromise elevation”. When lake levels exceed the compromise elevation, the pumps and gates on the Utah Lake pump station are left open to minimize flooding of lands adjacent to the lake.

Utah Lake also has five publicly accessible marinas that have protected areas of varying sizes for docks and ramps where treatments could be tested. These marinas include: American Fork, Saratoga Springs, Lindon Marina, Lincoln Beach, and the Utah Lake State Park marina. All of the treatments and monitoring were conducted in or immediately outside of the marina bays.

Figure 2. Study Area and Utah Lake project boundaries



2021 UTAH LAKE CONDITIONS

Like most reservoirs in Utah, lake levels in Utah Lake were somewhat low in 2021, and never reached compromise elevation. Low lake conditions are favorable to the development of HABs and recreational warning levels due to HABs persisting from early June through late September. Toxigenic cyanobacteria cell densities first exceeded the Warning Advisory level of 100,000 cells/mL in Provo Bay on June 11th with 267,000 cells/mL. The marinas remained safe until early July and a lake-wide Warning Advisory was ultimately issued by the Utah County Health Department on 7/13/2021. A couple of weeks later a Danger Advisory was issued for Lindon Marina with a toxigenic cyanobacteria cell count exceeding 78,000,000 cells/mL. At the time of the first treatment, lake-wide samples were consistently above Warning Advisory levels. This is important for a few reasons: 1. within treatment areas (marinas) it is easier to prevent high cyanobacteria densities, and use less treatment product, than it is to reduce them once they are already high; and 2. high cyanobacteria densities in the main body of Utah Lake pose a risk of reducing treatment duration due to intrusion into the marinas.

PLANNING AND LOGISTICS

Early and ongoing collaboration is among the most important findings of the pilot treatment project. Once the funding was awarded, FFSL and DWQ began collaborating on the development of an RFP so that it could be released as soon as the funding was made available, which allowed for the start of treatments within several weeks of awarding the contract. Despite this expedited process, an early bloom and planned event at Lindon Marina necessitated an early treatment, which was conducted by Alpine Technical Services (ATS).

Once the proposal from EutroPHIX was selected, weekly meetings were conducted to coordinate logistics, which facilitated early completion of the permitting process. As the treatments progressed, this coordination helped resource management agencies communicate observations and expectations to interested parties. This was also critical with coordination of monitoring, which can likely be conducted more efficiently now that these collaborative relationships have been established.

Despite the successful coordination efforts, a couple of areas of improvement were identified. Firstly, the disconnect between the state fiscal year and the HAB season did present logistical difficulties because treatments could not be applied until the HABs were already exhibiting extensive growth. In future projects, it will be critical to have funding and contractual agreements in place before the peak growing season to better maintain algal growth with treatments.

Secondly, one of the issues noted during the 2020 treatments was a rebound of HABs within several days of treatment, likely due to an influx of cells from the open waters reseeding the population within the marinas (Figure 1). As an element of the RFP selection process, EutroPHIX proposed the installation of bubble curtains as a potential way to minimize flow between the marinas and the open waters of Utah Lake. These installations pump air into diffusers along the bottom of the lake bed which arises as a physical curtain to minimize water exchange without impeding boat traffic. The installation was complicated by national supply chain limitations and the associated need to route electricity to the installation site. Nevertheless, a bubble curtain was installed that bisects Utah Lake State Park toward the end of the growing season (Figure 3). Having these curtains installed prior to treatments will be critical in isolating the treated marina from open water effects.

Figure 3. Bubble curtain installed to divide the Utah Lake State Park marina into inner and outer sections.

TREATMENT MONITORING

Monitoring conducted in association with the HAB treatments was designed to meet the following monitoring objectives:

- Provide quantitative evaluations of Utah Lake treatments funded by Utah's legislature.
- Evaluate the relative efficacy of proposed HAB treatments in decreasing bloom intensity at Utah Lake marinas.
- Evaluate any treatment effects that are potentially deleterious to desirable lake biota including potential increases in copper concentrations or the release of cyanotoxins into the water column as the dead algae cells senesce.
- Refine appropriate monitoring methods for evaluation of HAB treatments.

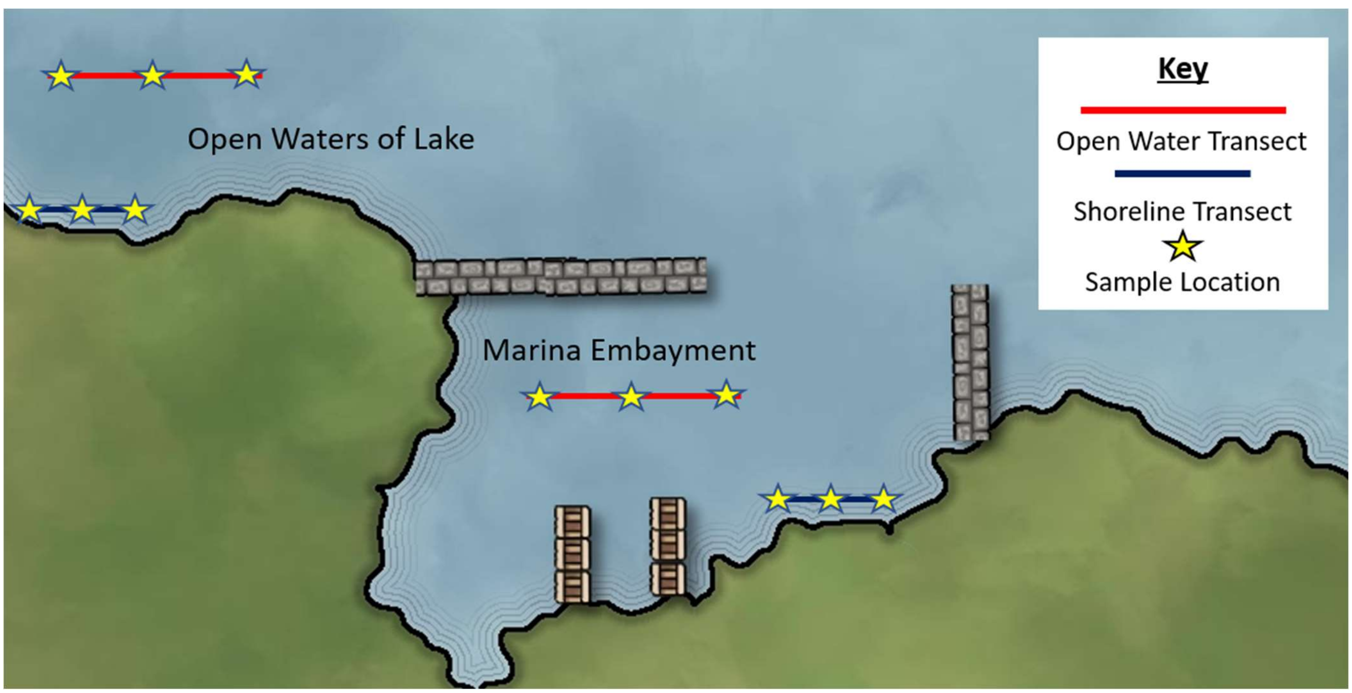
In addition to informing how to improve the efficiency and effectiveness of future treatments on Utah Lake, the information obtained from this exercise should also be helpful in improving any similar HAB at other lakes in Utah should the need arise in the future.

Methods

In 2021, HAB treatment response monitoring was conducted by DWQ to assess two treatments on Utah Lake. The first treatment was conducted by ATS and monitoring was conducted at Lindon Marina from July 7th through July 15$^{th.}$ The second treatment was conducted by EutroPHIX at American Fork Marina and monitoring was conducted from August 8th through August 16th.

Transects were established within and immediately outside (control) of the marinas where the treatments were conducted. Utah issues independent health advisories for open water and shoreline habitats, so separate transects were established at these habitats within and outside of the marinas so that treatment effects in these areas representing different recreation exposure can be independently evaluated (Figure 4). Three replicate samples were collected on the day prior to the treatment and then one and seven days following their application.

Figure 4. General layout of sample transects outside of the marinas to serve as controls and inside where treatments were conducted,



Boat-based applications were applied to each of Utah Lake's marinas approximately weekly throughout the summer of 2021 (Figure 5). For contractual reasons, one treatment was conducted by ATS in early July and the remainder were conducted by EutroPHIX. Two types of algaecide were used: Phycomycin, a peroxide-based treatment; and SeClear, a copper-based treatment. Copper is potentially toxic to fish and other organisms, so SeClear can only be applied every other week to minimize exposure risks. Alternating between these two types of treatments allowed more frequent application to keep recreational risks at the marinas as low as possible throughout the recreation season.

Figure 5. Application of treatments from boats (left) and dead algae cells observed within an hour following the treatments (right).

In 2021, EutroPHIX also conducted response monitoring for each of the approximately weekly treatments that they conducted at Utah Lake's marinas. Due to logistical and budgetary constraints, EutroPHIX monitoring was limited to immediately prior to and one day following treatments. DWQ partnered with EutroPHIX to enhance their monitoring for a treatment conducted at American Fork and a later treatment at Utah Lake State Park to evaluate the efficacy of bubble curtains that were installed in Utah Lake State Park State Park to determine if this technology could be used to reduce water exchange, potentially extending the effectiveness of the treatments (Figure 3). This effort also allowed DWQ to split samples with EutroPHIX so that the taxonomic composition for the two laboratories could be compared, which could potentially reduce laboratory processing costs on future treatment evaluations.

Results

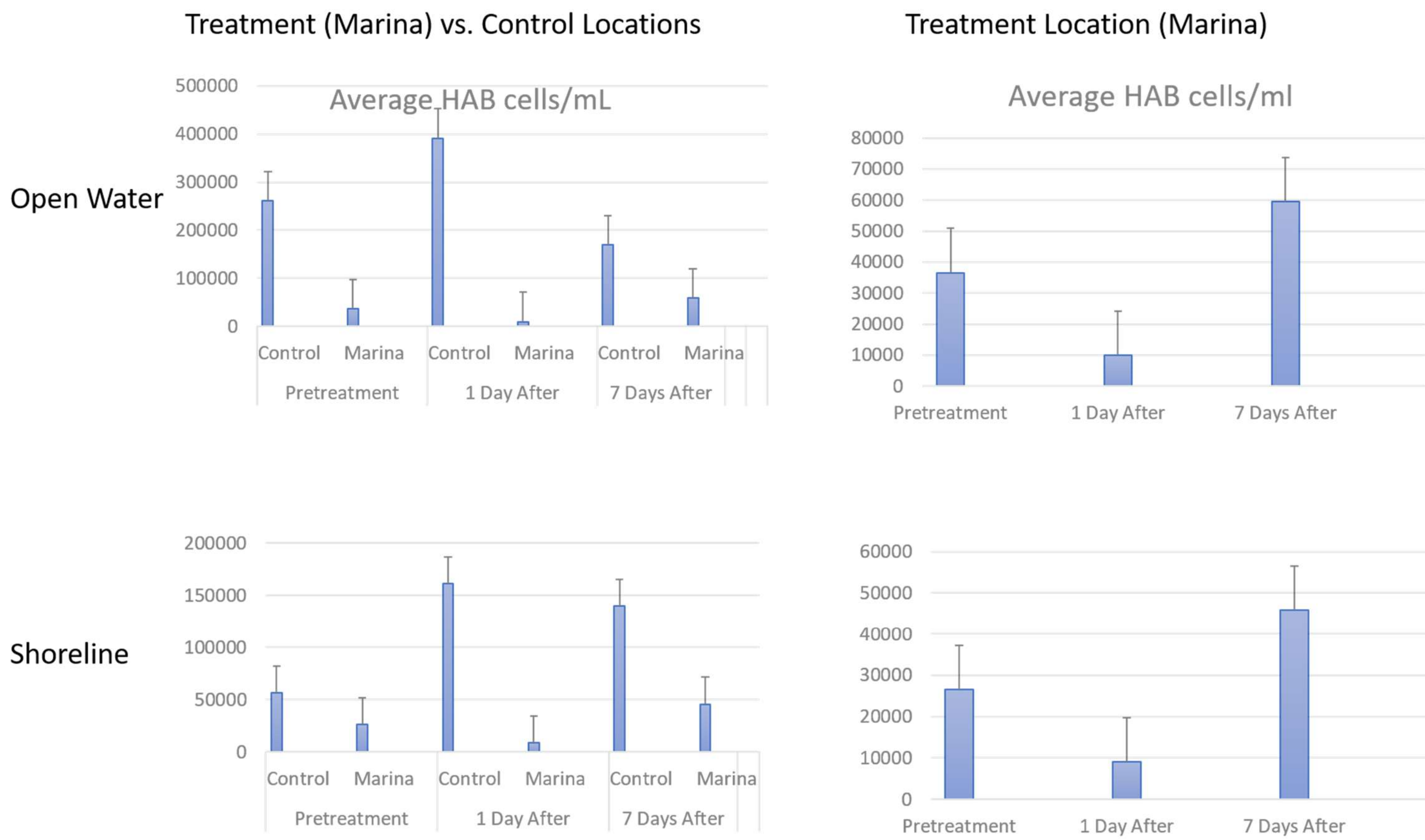
Almost all of the HAB treatments (25/29) that were conducted in 2021 were successful in reducing toxigenic cyanobacteria. However, only 34% of treatments were not successful at reducing HAB cell densities below the health advisory threshold of 100,000 cells/mL and the populations returned to pretreatment levels, sometimes exceeding pretreatment densities within a week of applications. Despite these shortcomings the treatments did reduce exposure risks and marina managers reported positive comments from recreationists due to improvements in water clarity (Figure 6). This section provides a detailed analysis of how cyanobacteria populations responded to two treatments. Also presented is an evaluation of how bubble curtains could potentially be used to increase the longevity of treatments conducted at Utah Lake marinas.

Figure 6. An example of the visual difference observed during 2021 HAB treatments.

Lindon Marina Treatment

In the open water of the Lindon Marina embayment, the treatment reduced pretreatment HAB cells by 73% in the day following the treatment from 37,000 ± 7,000 cells/mL (± 1 SD, N = 3) to 10,000 ± 1000 cells/mL (Figure 7). However, within 7 days, HAB populations within the marina rebounded by 500% to 60,000 ± 1000 cells/mL, exceeding the cell density observed prior to conducting the treatments.

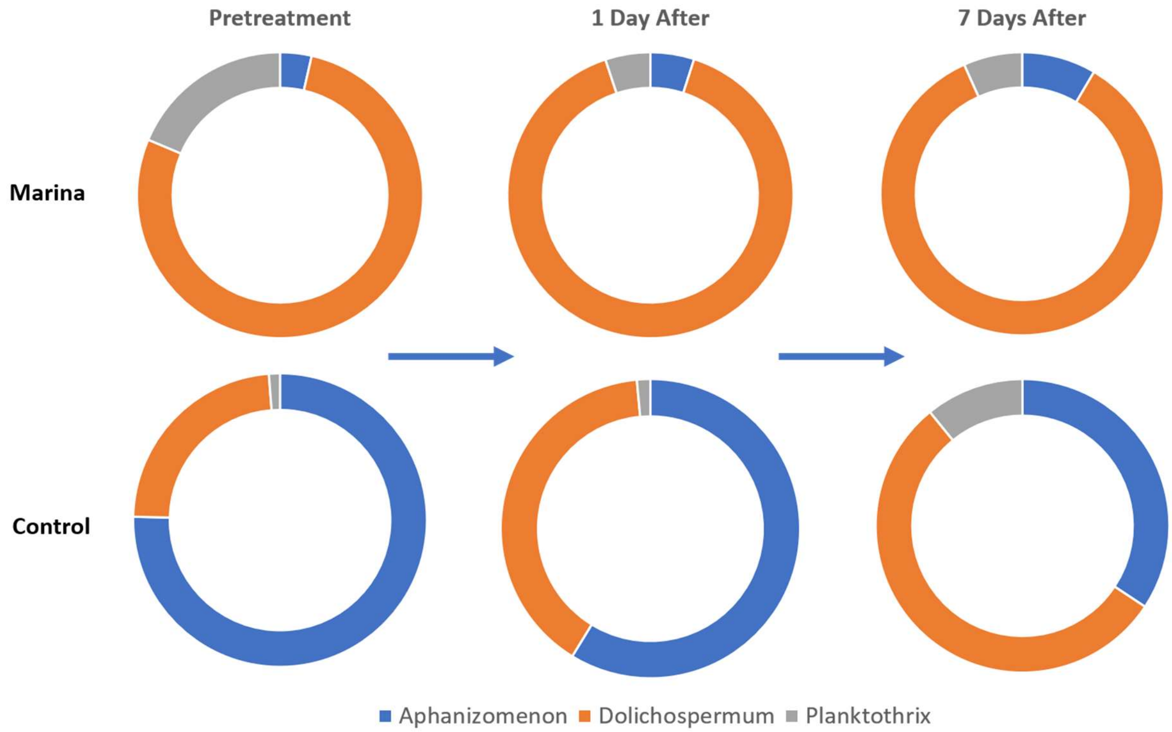
Figure 7. Comparison of the average algae density observed at Lindon Marina between treatments and control transects (left panels) and in the marinas where treatments were conducted (right panels) for open water (top) and shoreline habitats (bottom). Error bars are one standard error.



HAB densities were somewhat lower at the beaches along the shoreline, but treatment response patterns were nearly identical. The treatments resulted in a 66% decrease in HAB density the day following the treatments from 26,000 ± 1000 cells/mL to 9,000 ± 2,000 cells/mL. The subsequent increase in HAB density was also rapid, with a 400% increase from one to seven days following the treatment.

For both open water and shoreline habitats, HAB cell counts were much higher at the control locations than within the marina where the treatment was conducted across all monitoring events (Figure 7). HAB density was considerably higher at seven days than immediately prior to the treatments at both treatment (marina) and control locations. This suggests that the large rebound observed in Lindon Marina was likely not directly related to the treatment itself and simply reflects a change in conditions favorable to HAB growth and potentially an incursion of cyanobacteria from the open waters of Utah Lake into the marina.

Figure 8. Relative biomass for the most abundant toxigenic taxa in open water samples collected at Lindon Marina where the treatments were conducted (top panels) and immediately outside the marina (bottom panels) before and following their application.



Data collected in 2020 revealed a couple of circumstances where the treatments may have resulted in changes in the dominant toxigenic HAB taxa after post-treatment HAB densities rebounded. This could be problematic if treatments resulted in an increase in the density of taxa that are more toxic than previously present. The treatment at Lindon Marina did not seem to alter the relative biomass of HAB taxa (Figure 8). In the marina, *Dolichospermum* was the dominant taxon prior and subsequent to the conduction of the HAB treatment. In contrast, appreciable changes were observed at the control location in the open water of Utah Lake with a gradual shift in dominance from *Aphanizomenon* toward *Dolichospermum*. This change in HAB dominance over the week of monitoring was likely the result of changing lake conditions, or the natural phenology of the cyanobacteria assemblage, because the control location was not affected by the treatments. This observation highlights the challenges in attribution of changes to the treatment in a dynamic ecosystem like Utah Lake.

For the water quality parameters monitored, only copper potentially exceeded water quality standards (Table 1). Utah's acute copper criterion is based on a one-hour average and the chronic criterion is based on a 4-day average. Samples were collected at pre, 1-day, and 7-day post treatment. As expected, prior to the treatment, average copper concentrations were well below the acute (50 μg/L) and chronic copper criterion (29 μg/L) in the open water within and outside of the marina. The day following the treatment copper concentrations within the marina exceeded both the acute and chronic copper water quality criteria. However, after 7 days average copper concentrations in all of these locations declined to levels below the copper criteria (Table 1). After a week, copper concentrations remained slightly higher than prior to the treatment. Only short-term excursions to water quality standards were observed, but long-term trends in copper concentrations should continue to be tracked, especially if these treatments will be repeated over time. Finally, there was no evidence for the release of cyanotoxins into the water column from the treatment. Average microcystin concentrations were similarly low in all habitats and locations (<0.7 μg/L) and those within the marina slightly declined during the monitoring period.

Table 1. Copper concentrations before and after the Lindon Marina treatment.

Date	Sequence	Location	Habitat	Sample Location	Average Concentration (µg/L)	Standard Deviation
7/7/2021	Pretreatment	Marina	OW	Surface	2.0	0.2
				Benthic	2.5	1.6
			Shoreline	Surface	2.5	0.6
		Control	OW	Surface	1.4	0.1
				Benthic	3.7	4.3
			Shoreline	Surface	1.6	0.2
7/9/2021	1 Day After	Marina	OW	Surface	70.9*	11.5
				Benthic	57.1*	18.0
			Shoreline	Surface	93.2*	5.2
		Control	OW	Surface	1.7	0.2
				Benthic	2.9	0.1
			Shoreline	Surface	4.0	0.5
7/15/2021	7 Days After	Marina	OW	Surface	2.9	0.1
				Benthic	2.9	0.1
			Shoreline	Surface	2.3	0.1
		Control	OW	Surface	1.4	0.2
				Benthic	1.3	0.0
			Shoreline	Surface	1.7	0.0

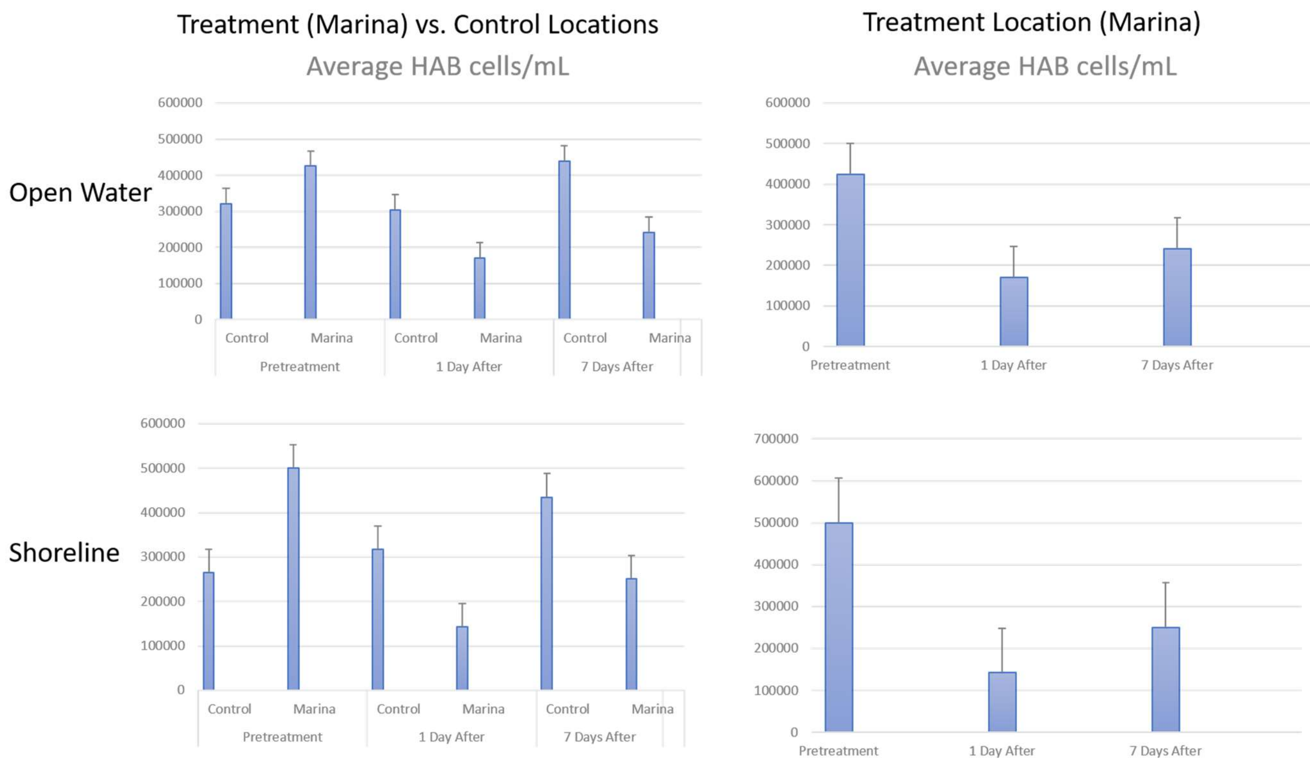
* Excursion of 50 μg/L (1-hour average criterion) and 29 μg/L (4-day average criterion) .

American Fork Marina Treatment

Pretreatment HAB cell counts were almost ten times higher (425,000 ± 24,000) in open waters of the American Fork Marina than the cell densities observed prior to the Lindon Marina treatment. On average, a 60% reduction in open water HAB cells (171,000 ± 58,000) was observed the day following the treatment (Figure 9). However, even with these reductions the marina remained above the health advisory level of 100,000 HAB cells/mL. Unlike the Lindon Marina, the density of HAB cells never returned to pretreatment levels seven days following the treatment, increasing 41% to 241,000 ± 20,000 cell/mL. During the same period, HAB densities also occurred in the open water control samples, which suggests that the treatment continued to suppress cyanobacteria numbers.

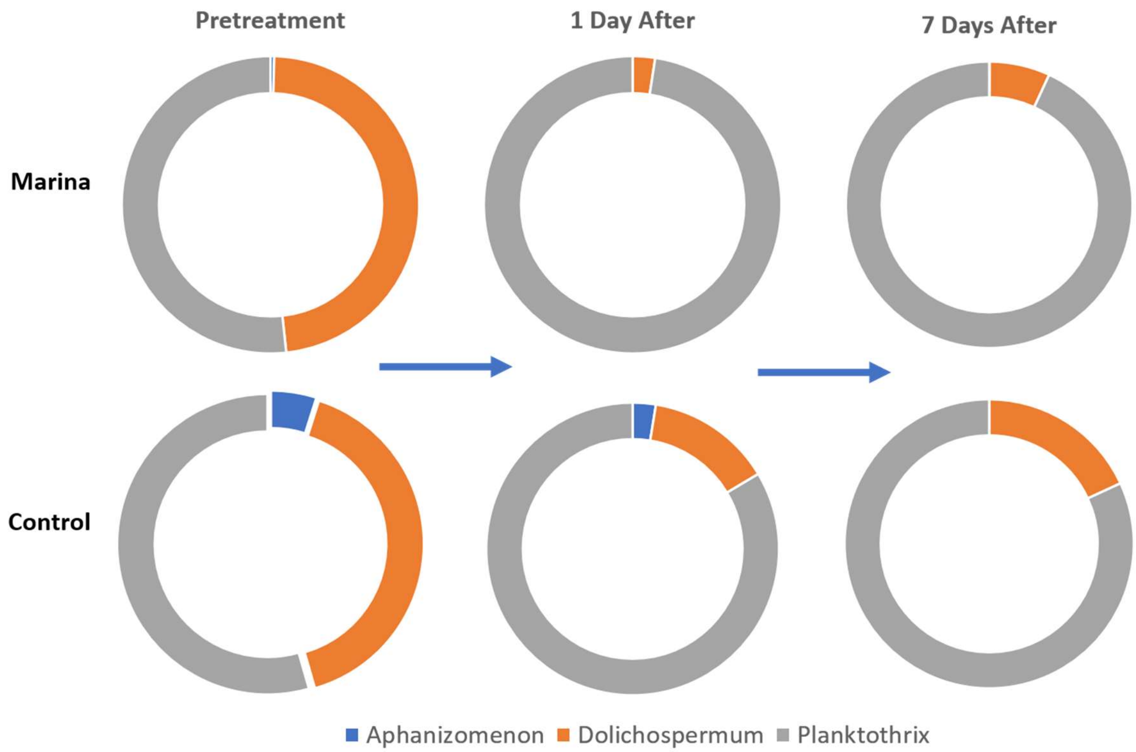
Shoreline pretreatment HAB densities (500,000 ± 47,000) in the marina were a little higher and more variable than samples collected in the open waters. The treatment was slightly more effective in reducing the density of shoreline HABs. A 72% reduction in HAB density to 142,000 ± 24,000 cells/mL. was observed the day after the treatment. However, there was also a relatively larger (76%) increase seven days following the treatment to 250,000 ± 10,000 cell/mL.

Figure 9. Comparison of the average algae density observed at American Fork Marina between treatments and control transects (left panels) and in the marinas where treatments were conducted (right panels) for open water (top) and shoreline habitats (bottom). Error bars are one standard error.



The HAB taxonomic composition of the dominant taxa changed considerably over the eight-day monitoring period. Prior to the treatment, the biomass of HAB taxa was approximately equally split between *Dolichospermum* and *Planktothrix* (Figure 10). A couple of days later, *Planktothrix* had taken over as the dominant HAB taxon. This trend occurred at the open water control site too, albeit slightly less pronounced, so this change likely reflects changing conditions in Utah Lake as opposed to changes caused by the HAB treatment. Based on the control sites collected at Lindon Marina approximately one month earlier, Utah Lake seems to be transitioning its composition for the third time in 2021.

Figure 10. Relative biomass for the most abundant toxigenic taxa in open water samples collected at Lindon Marina where the treatments were conducted (top panels) and immediately outside the marina (bottom panels) before and following their application.



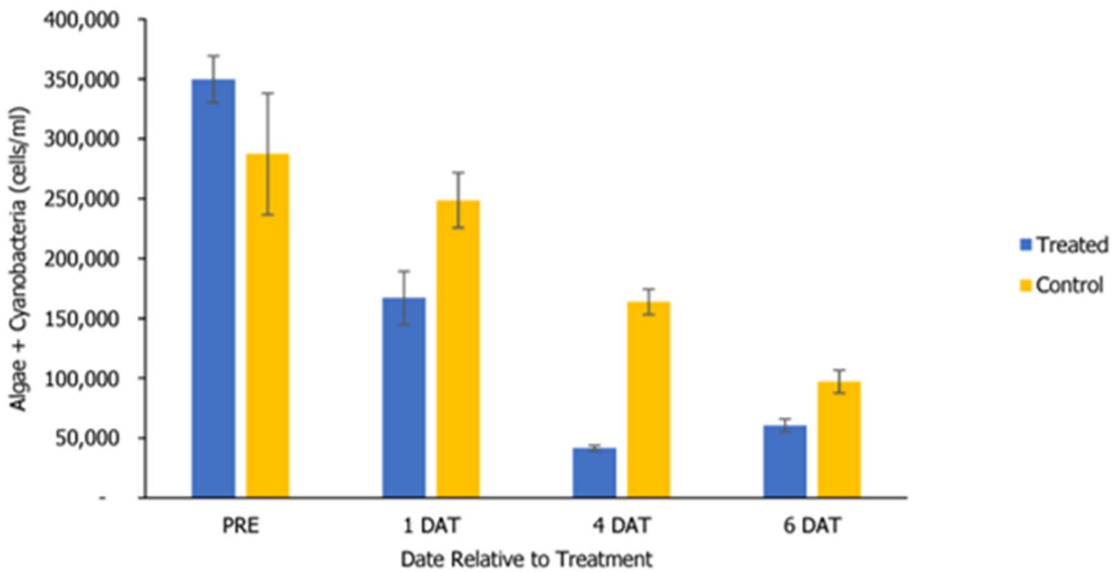
Unintended outcomes in the American Fork Marina were similar to those observed at the Lindon Marina. A 4-day average (chronic) copper criterion excursion was observed in the marina the day following the treatment, although the average copper concentration excursions were lower for the American Fork Marina treatment (Table 2). After one week, copper concentrations fell below the criterion, but never dropped to those observed prior to the treatment. Microcystin concentrations were also low (<0.8 μg/L), without any distinct differences between treatment and control sample locations, which suggests that microcystin-release was not an issue by the HAB treatment at this marina.

Table 2. Copper concentrations before and after the Lindon Marina treatment.						
Date	**Sequence**	**Location**	**Habitat**	**Sample Location**	**Average Concentration (µg/L)**	**Standard Deviation**
8/10/2021	Pretreatment	Marina	OW	Surface	1.1	0.1
				Benthic	1.1	0.03
			Shoreline	Surface	1.1	0.1
		Control	OW	Surface	1.1	0.1
				Benthic	1.2	0.1
			Shoreline	Surface	1.3	0.1
8/12/2021	1 Day After	Marina	OW	Surface	32.3*	1.3
				Benthic	23	4
			Shoreline	Surface	30.1*	8.6
		Control	OW	Surface	1.9	0.8
				Benthic	1.3	0.1
			Shoreline	Surface	1.2	0.1
8/16/2021	7 Days After	Marina	OW	Surface	4.5	0.5
				Benthic	4.2	0.6
			Shoreline	Surface	4.8	0.1
		Control	OW	Surface	1.2	0.04
				Benthic	1.2	0.1
			Shoreline	Surface	1.5	0.6
* Excursion of 29 μg/L (4-day average criterion)						

Bubble Curtain Evaluation

Bubble curtains have been demonstrated to minimize water exchange, while also allowing passage of boats. They work by pumping air through diffusers placed on the lake bed. Once bubble curtains were installed to divide the Utah Lake State Park maina into two sections, a treatment was conducted and HAB response was evaluated in both sections of the marina embayment. The density of algae and cyanobacteria cells declined in the days following the treatment from about 350,000 cells/mL to a low of about 50,000 cells/mL after four days (Figure 11). Declines of cyanobacteria density also occurred in the portion of the embayment that was exposed to the open waters of Utah Lake (control), but to a lesser extent, suggesting that the bubble curtains were working to extend the longevity of HAB treatments. Nonetheless, bubble curtain installments have known limitations, particularly when exposed to a strong current, which are common on Utah Lake due to the long fetch. To complement the utility of these curtains, some marina openings could be physically altered to either reorient away from a common current direction or enhanced with current deflectors.

Figure 11. Density of algae cells at the Utah Lake State Park marina within the area of the marina protected by the bubble curtain (blue bars) and the area exposed to Utah Lake (yellow bars), before (PRE) and then one, four and six days (1DAT, 4DAT, 6DAT) following HAB treatments.



SUMMARY AND NEXT STEPS

The objective of the 2021 treatments was to focus on the marinas to minimize human health risks in the areas most frequently used for recreational purposes. This was successful in the sense that almost all treatments reduced cyanobacteria densities. However, it was also the case that some of the treatments were never able to reduce HAB levels below the health advisory level of 100,000 cells/mL. This means that treatments may need to begin earlier in the season and may need to be applied more frequently to meet management objectives. While potentially not practical to apply treatments from boats more frequently than weekly, it may be possible to install automated application equipment if needed. Ideally, potential solutions such as this would be evaluated through a lakeside treatment planning process.

Unfortunately, the marinas are not isolated from the open waters of Utah Lake, so incursions of cyanobacteria back into the marina embayments likely occurred, which is an important determinant of the amount of time treatments are successful in reducing cyanobacteria density. For example, the treatment events monitored in 2021 showed the density of cyanobacteria exceeding pretreatment levels within a week, whereas the increase in cyanobacteria density at the American Fork Marina never returned to pretreatment levels. The frequency of treatments necessary to control cyanobacteria abundance will likely vary from one marina to the next and may differ over the course of a recreation season due to factors such as weather conditions or lake levels.

Minimizing the incursion of cyanobacteria from the lake back to the marinas would likely reduce the frequency of treatments necessary to control HABs in the Utah Lake marinas. This could potentially be accomplished through installation of bubble curtains as demonstrated at the Utah Lake State Park marina in 2021. Another possibility would be creating a wind/wave barrier at marina entrances, potentially using material dredged from the marina embayments. The right combination of these approaches will likely differ among Utah Lake marinas and should be evaluated as part of a comprehensive treatment planning process for Utah Lake.

Utah Lake is a dynamic ecosystem and the dominant cyanobacteria change seasonally and from year to year. The dominant taxa shifted three times over the course of the five weeks of treatment monitoring evaluated in this interim report. This is relevant to algae treatments in a couple of ways. First, different taxa may respond differently to different treatments and understanding the extent to which this is true could inform treatment type, dosing, or the frequency of treatments. Second, some toxigenic cyanobacteria pose a greater threat to human health than others, so understanding whether or not treatments alter HAB composition is important. Treatment monitoring from 2020 revealed a shift to potentially more toxic taxa when the cyanobacteria returned to pretreatment densities. The dominant taxa also shifted during the 2021 treatments, but similar trends occurred at the control locations, which suggests that the compositional changes were more related to natural cyanobacterial phenology within the lake rather than to the treatments. It is difficult to generalize these relationships with a limited number of monitoring events; however, given the potential importance of changes in the taxonomic composition of cyanobacteria it would be prudent to continue composition monitoring for future treatments at both treatment and control locations.

Ultimately, the most effective way to diminish the harmful impacts to recreational uses is reducing nitrogen and phosphorus inputs to the lake, but this could potentially be augmented with HAB treatments. If treatments continue to be used to control HABs at Utah Lake, it will be important to continue monitoring ecosystem responses. This will help identify unintended outcomes such as seasonal or year-to-year accumulation of copper or other compounds in lake sediment. Equally important is gaining a more complete understanding of how treatments can be applied in the most effective and cost-efficient manner possible, not only within Utah Lake but to other lakes experiencing HABs throughout Utah.