Journal of Environmental Science and Engineering A 6 (2017) 111-119
doi:10.17265/2162-5298/2017.03.001

# Quantification of Nutrient Assimilative Capacity of *Chara* (sp.) in a Previously Hypereutrophic Lake in Southwest Florida (USA): Implications for Lake Management

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**Abstract:** The Sunshine Lake/Sunrise Waterway System, located in Southwest Florida (USA) previously experienced extensive and persistent algal blooms, with noxious odors and deep organic-rich sediments. This algal bloom was addressed via a lake-wide dredging project to remove the material from the lake bottom. A contributing factor to the algal bloom is elevated phosphorus in stormwater runoff, likely due to naturally phosphorus-rich geology in the surrounding watershed. Due to the naturally elevated phosphorus supply, excessive nutrient loads will likely continue in the future. An ongoing monitoring program, initiated after the dredging of the lake, determined that a type of algae (*Chara* sp.) other than that which caused the initial bloom had established itself by October 2015. This plant biomass is considered an alternative destination for incoming nutrient loads, and as such should be managed, rather than eliminated via the use of herbicides. The abundance and nutrient content of the mass of *Chara* sp. in the lake and waterway was estimated, and the amount of external nutrient load that would be removed from the lake with physical harvesting of *Chara* sp. was quantified. The cost-effectiveness of nutrient removal via physical harvesting of *Chara* sp. was then compared against typical stormwater treatment ponds.

**Key words:** Lake water quality, eutrophication, phosphorus, restoration strategies.

## 1. Introduction

The Sunshine Lake/Sunrise Waterway System, in Southwest Florida (USA) is approximately 4.7 ha in size, with a contributing watershed of approximately 120 ha, for a watershed to open water ratio of 26 to 1 [1]. According to long-term residents, the Sunshine Lake/Sunrise Waterway System changed from a relatively healthy waterway with good water clarity and a mostly sandy bottom to an algae-clogged lake, with noxious odors and a deep mat of algae-covered sediments [1].

The algal bloom was determined to be due to a collection of cyanobacteria (aka blue-green algae) that was dominated by the species *Aphanothece conglomerata* [1]. At its height, the algal mat occupied approximately 50 percent of the lake's volume [1]. The quantity of the nutrients nitrogen and phosphorus required to account for the algal biomass was derived, and then compared to a variety of potential nutrient sources. After the collection, analysis and interpretation of data on stormwater runoff, groundwater seepage and other sources, it was determined that the factor most likely responsible for the algal bloom was a combination of stormwater runoff and groundwater seepage of phosphorous, and that the high phosphorous loads were due to natural geologic features [1]. As the nutrient loads responsible

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for the algal bloom were determined to be mostly natural, the lake and waterway remain susceptible to a recurrence of the initial problematic algal bloom. As part of an ongoing monitoring program, it was found that a more desirable form of algae had become established in the lake, a green algal species of the genus *Chara*. This study quantified the nutrient content of the biomass of *Chara* sp. within the lake, and compared it to estimated nutrient loads from external sources. As well, the cost-effectiveness of nutrient management through the physical removal of *Chara* was quantified, and compared to the cost-effectiveness of more traditional nutrient management strategies.

## 2. Materials and Methods

Quarterly sampling of the amount of algae at 50 stations located in the lake and waterway was undertaken at the locations shown in Fig. 1. The northernmost 35 stations are located in the somewhat wider portions, referred to as Sunshine Lake, while the southernmost 15 stations are located in the narrower portion, referred to as the Sunrise Waterway. While the lake and waterway are hydrologically connected, there is a weir structure that prevents water movement from the Waterway back up into the Lake itself.

At each of 50 randomly-chosen stations (35 in the lake and 15 in the waterway), a pole with a flat plate

**Fig. 1 Location of sampling sites for benthic algal assessment of Sunshine Lake and the Sunrise Waterway.**

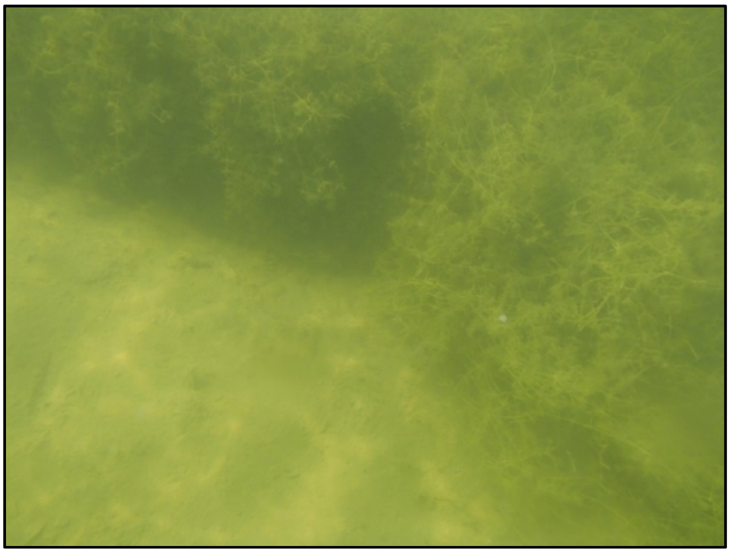

**Fig. 2 Underwater photograph from within Sunshine Lake, showing *Chara* sp. growing on the lake bottom.**

affixed to the bottom was lowered into the water. The pole was lowered into the water column until it reached the top of the algal mat, and the depth recorded. The pole was then lowered through the algal mat until the point of refusal, which was recorded as the bottom of the lake and waterway.

Sampling was undertaken on the following dates: 10/16/2015, 1/18/2016, 4/7/2016, 7/6/2016, 11/29/2016 and 3/3/2017. For each date sampled, there was no evidence of the prior benthic algal mat, which in the past was dominated by the cyanobacterial species *Aphanothece conglomerata*. Instead, after the dredging of the lake, the algal biomass was of a species of green algae in the genus *Chara*, also known as musk grass, due to its strong, garlic-like odor (see Fig. 2). Musk grass is native to Florida, and although it can become problematic to navigation and flood control if it becomes overly abundant, it provides good habitat for fish and wildlife, and is not considered a nuisance species.

The amount of *Chara* in the lake and waterway was quantified in two ways. The first metric was in terms of the percent of the bottom where *Chara* was found, which is determined by the frequency with which *Chara* was encountered (i.e., 5 of 15 sites would equal 33 percent coverage). In addition, the percent of the volume of water occupied by *Chara* was estimated by additionally determining the portion of the water column with *Chara*. In this way, high coverage of *Chara* (in terms of being found at most locations) would not necessarily translate to it being a dominant feature of the lake, if the growth form was that of diminutive plants. Conversely, a lower frequency of occurrence could result in a substantial occupation of the water column, if those more rarely occurring plants were large enough.

The pattern of abundance of *Chara* sp. was turned into a lake-wide estimate for each of the sampling events, based on applying the percentage stations where *Chara* was found multiplied by the size of the lake and waterway. This resulted in estimates of both the amount of lake bottom with *Chara*, as well as the amount of the lake's water column that was occupied by the plant. These estimates of coverage were then compared to a data set compiled by prior researchers [2]. The data summary report used compiled data from 12 studies which quantified the biomass of *Chara* in various locations, in units of g dry weight $m^2$ [2]. The authors of the summary report [2] showed results from 15 studies that provided estimates of the nitrogen content (percent of dry weight) and 12 studies that examined the phosphorous content (also in units of percent of dry weight). Average values of biomass and nutrient content from that same study were then used for further analyses. The percentage of lake bottom occupied by *Chara* sp. was then combined with the average biomass value [2] to estimate the biomass of *Chara* in the lake and waterway for each sampling date. Those lake-wide biomass estimates were then multiplied by the average nitrogen and phosphorous contents from the summary report [2] to derive system-wide estimates of the amount of nitrogen and phosphorus contained within the *Chara* found in the lake and waterway.

The amount of nitrogen and phosphorus within the *Chara* biomass in the lake and waterway was then compared to estimates of the annual load of nitrogen and phosphorous into the lake and waterway [1].

Finally, the amount of nutrient removal brought about with the physical removal of *Chara* biomass was converted into a cost (USD) per kg of nitrogen and phosphorus, based on a *Chara* removal effort conducted in 2016 in the lake and waterway. The dollar per kg costs for *Chara* removal were then compared to similar cost estimates for more traditional nutrient reduction strategies undertaken by local, regional and state agencies in Florida.

## 3. Results

Due to the change in lake morphology, from north to south, it was decided that the biomass of *Chara* would be tracked individually for the northernmost 35 stations (i.e., “lake” sites) vs. the 15 southernmost stations (i.e., “waterway” sites).

The percentage of the lake and waterway where *Chara* was found remained higher than 60 percent for both locations, from October 2015 to April 2016 (Fig. 3). From July 2016 until March 2017, *Chara* became a more common feature of the waterway, while coverage decreased substantially in the lake. By March of 2017, *Chara* was no longer encountered in the lake itself, while it was still found at more than 80 percent of stations in the waterway.

When the percentage of the water column occupied by *Chara* was calculated, the lake and waterway did not show as distinct a pattern as was seen in percent occurrence (Fig. 4). The reason for the discrepancy between the patterns shown for the waterway stations, comparing Figs. 3 and 4, is that individual plants were much smaller in November 2016 and March 2017, compared to earlier sampling events. For example, in October 2015, individual plants grew to an average height of 82 cm off the bottom in the waterway. By March 2017, the average plant was only 27 cm in height. Consequently, similar frequencies of occurrence could result in much lower amounts of biomass, since remaining plants were much smaller in later sampling events.

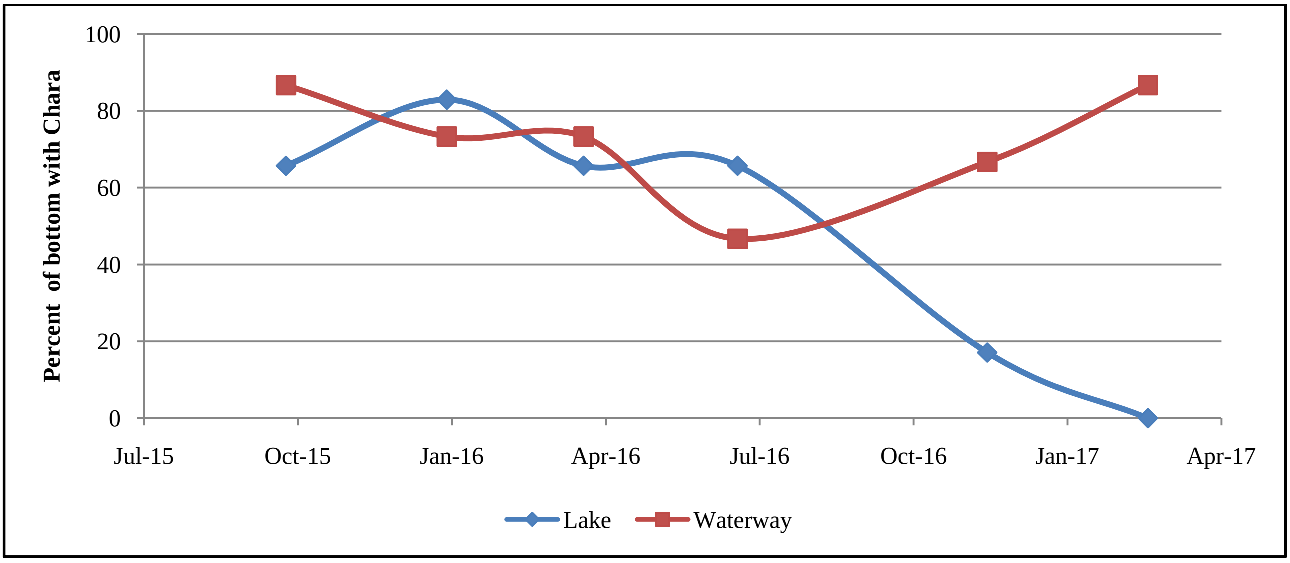

**Fig. 3 Frequency of occurrence (percentage) of *Chara* sp. growing in the lake and waterway.**

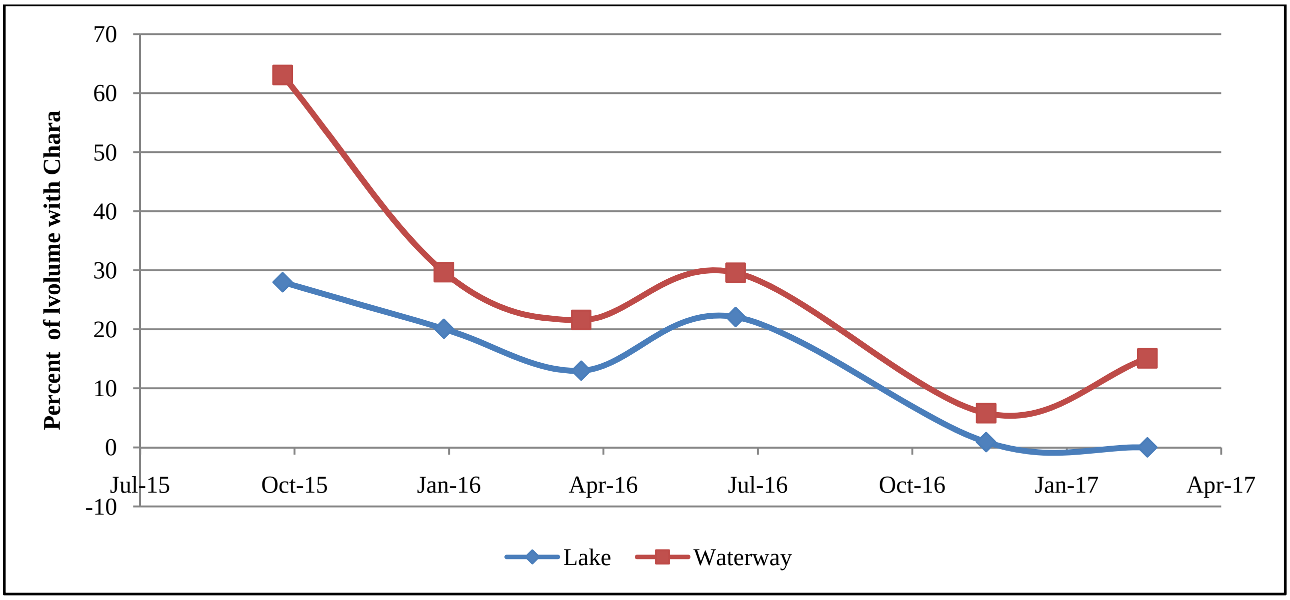

**Fig. 4 Percent of water column occupied by C*hara* sp. growing in the lake and waterway.**

**Table 1 Biomass, nutrient content, area-normalized nitrogen and phosphorus estimates for *Chara* sp., based on lowest values, highest values and the mean value for studies listed in Kufel (2002).**

| Value | *Chara* abundance | Nitrogen content | Phosphorous content | Area-normalized nutrient content | |
|---|---|---|---|---|---|
| | ($g{\cdot}dw/m^2$) | ($mg/g{\cdot}dw$) | ($mg/g{\cdot}dw$) | ($g{\cdot}N/m^2$) | ($g{\cdot}P/m^2$) |
| Low range | 58 | 2.43 | 0.2 | 141 | 12 |
| High range | 500 | 33 | 3.1 | 16,500 | 1,550 |
| Mean | 254 | 13.8 | 2.1 | 3,505 | 533 |

Based on literature from more than a dozen studies on *Chara* biomass and nutrient content [2], an estimate was made of the likely nutrient content that would be expected to be contained within the biomass of *Chara* in the lake and waterway. While there were no biomass estimates made for this study, descriptions of the studies included in the summary report examined suggest that such studies were made for waterways with similar water depths, with plants that could be as dominant a feature as what was recorded in the latter part of 2015. For the purposes of this study, the mean value of all studies in the summary report was used to develop an estimate of the area-normalized nutrient content for *Chara* in the lake and waterway (Table 1).

In Southwest Florida (USA), state agencies have developed a system to determine the cost-effectiveness of reducing nitrogen and phosphorus loads from stormwater runoff, and how various projects would be expected to reduce such loads. The typical approach taken is the use of stormwater treatment ponds. In their assessments, state agencies take into account the cost of the project, which when divided by the expected reduction in nutrient loads results in an estimate of the amount of money spent per unit weight of nutrient removal. Since the typical project approach involves a stormwater treatment pond, it is anticipated that the pond will involve an upfront construction cost, but little to no maintenance over the next few years. As a way to “normalize” cost-efficiencies for the expected project duration, the nutrient removal amount is estimated over a 20-year time span (the expected lifespan of such ponds) while the project cost is a one-time event. Table 2 represents a summary of data from projects tentatively approved for funding for 2017 by the Southwest Florida Water Management District.

**Table 2 Kg of nitrogen and phosphorus removal, project cost, and cost efficiencies over one-year and 20-year time frames for various stormwater retrofit projects. TN = Total Nitrogen, TP = Total Phosphorus. Currency is in 2017 USD. 20-year values represent one-time cost of construction divided by the sum of nitrogen and phosphorus loads expected to be reduced over 20 years.**

| Project | kg TN removed/yr | kg TP removed/yr | Cost | $/kg TN | $/kg TP | $/kg TN | $/kg TP |
|---|---|---|---|---|---|---|---|
| | | | | first yr | | over 20 yrs | |
| N831 | NA | 2.3 | $200,000 | NA | $88,185 | NA | $4,409 |
| N676 | 95.3 | 13.6 | $2,630,300 | $27,613 | $193,294 | $1,381 | $9,665 |
| W773 | NA | 65.3 | $2,352,000 | NA | $36,009 | NA | $1,800 |
| N674 | 20.0 | 2.3 | $620,000 | $31,065 | $273,373 | $1,553 | $13,669 |
| N788 | 10.4 | 1.8 | $1,650,000 | $158,158 | $909,407 | $7,908 | $45,470 |
| N793 | 26.8 | 3.2 | $3,000,000 | $112,099 | $944,838 | $5,605 | $47,242 |
| Mean | 38.1 | 14.7 | $1,742,050 | $82,234 | $407,518 | $4,112 | $20,376 |

The mean nutrient removal amounts achieved with the six projects listed in Table 2 are 38.1 kg/yr and 14.7 kg/yr for nitrogen and phosphorus, respectively. Over the expected timeline of 20 years, and converted to metric units, the mean cost-effectiveness of the six projects listed in Table 2 are $4,112 per year per kg for nitrogen, and $20,376 per year per kg for phosphorus.

## 4. Discussion

### *4.1 Spatial and Temporal Trends in Abundance of Chara sp.*

In both the lake and waterway, the amount of the lake's volume occupied by *Chara* sp. declined substantially from October 2015 to March 2017. Although both systems showed a separate and smaller increase in July 2016, the increase was not sustained. The diverging patterns shown in Figs. 3 and 4 are explained by the height of the plants, which is correlated with the biomass of the plants. Although *Chara* was a common feature of the waterway in both November 2016 and March 2017, the plants were quite short, averaging less than 30 cm in height. Thus, while *Chara* was widely distributed, it occupied less than 20 percent of the volume of the lake, as the plants were reduced in size in later months.

In response to concerns from the general public about the amount of *Chara* sp. growing in the lake and waterway, the local government undertook two management actions. The first was to hire a contractor to physically remove the plant biomass from the lake, which occurred during the months of November 2015 to January 2016. The second management action was to add triploid grass carp (*Ctenopharyngodon idella*). Grass carp are herbivorous fish, and they have been widely used as a relatively inexpensive way to reduce the amount of plant biomass in lakes in Florida, avoiding the need for the application of herbicides. The term "triploid" refers to fish that have three copies of each chromosome (not the usual two) which reflects these fish having been genetically altered to prevent them from reproducing and thus spreading to other lakes or increasing to problematic abundances. Triploid grass carp were added to the lake and waterway in February 2016, just after the last of the physical removal of *Chara* by contractors.

Although the timing of physical removal of *Chara* and the addition of triploid grass carp are somewhat close to each other, the second sampling event occurred after the contractors had completed the physical removal of *Chara*, but before any triploid grass carp were added. Thus, changes in the abundance of *Chara* between October 2015 and January 2016 cannot be attributed to the addition of triploid grass carp. Instead, the decline in coverage is likely some combination of the effects of seasonal changes in biomass, combined with the reduction in coverage due to the physical removal of *Chara*.

Between October 2015 and January 2016, the physical removal of *Chara* did not seem to have a large impact on the percent of the lake bottom with *Chara* (Fig. 3). However, the percent of the water column occupied by *Chara* decreased by an average of 44 percent, for the lake and waterway combined. The volume of the lake and waterway occupied by *Chara* continued to decrease to April 2016, followed by increases in July 2016, and then a decrease to the lowest average levels, recorded in November 2016. By March 2017, *Chara* was not found in the lake, while it was found at more than 80 percent of surveyed sites in the waterway (Fig. 3). Despite its widespread abundance in the waterway in March 2017, the individual plants were much smaller than in 2015 and 2016. As a result, although *Chara* was encountered at more than 80 percent of waterway sites in both October 2015 and March 2017, the percentage of the water column occupied by *Chara* decreased from more than 60 percent to less than 20 percent.

### *4.2 Nutrient Contents and Destinations*

GIS (Geographic Information System)-based mapping techniques were used to estimate the size of the waterbodies, which were then multiplied by the percent frequency of occurrence of *Chara* in October 2015 (72 percent) to develop an estimate of the amount of *Chara* in the combined lake and waterway of 3.56 ha (equal to 35,600 square meters). This estimate of *Chara* abundance was then multiplied by the literature-derived average values for area-normalized nutrient contents (Table 1) to develop an estimate of the amount of nitrogen and phosphorous contained within the *Chara* meadows in the lake and waterway. Using this approach, it was estimated that the amount of nitrogen and phosphorous contained within the *Chara* in the lake and waterway were 125 and 19 kg, respectively, for nitrogen and phosphorus.

Based on the pollutant loading model conducted for the lake and waterway [1], the estimated annual nutrient loads are 106 and 15 kg of nitrogen and phosphorus, respectively. Thus, the amount of nitrogen and phosphorus contained within the *Chara* in the lake and waterway in October 2015 accounts for 118 and 127 percent of the estimated annual loads of nitrogen and phosphorus, respectively. While there is uncertainty associated with each step of the process described above, it is likely that the amount of *Chara* in the lake and waterway was, at least in October 2015, a “sink” for much of the nitrogen and phosphorus loads from stormwater runoff and groundwater seepage.

Based on the differences in coverage between October 2015 and January 2016, which were the sampling dates before and after contractors removed *Chara* from the lake and waterway, it was estimated that the amount of *Chara* in the lake declined by approximately 44 percent. This would equal a removal of nitrogen and phosphorus from the lake of 54.9 and 8.2 kg, respectively, equivalent to 47 and 55 percent of the estimated annual nitrogen and phosphorus loads to the lake and waterway, respectively [1]. Consequently, it would appear that the physical removal of *Chara* biomass from the lake and waterway could be a useful tool for removing a substantial amount of the annual nutrient load entering the lake via stormwater runoff and groundwater seepage.

### *4.3 Cost Effectiveness of Nutrient Abatement Techniques*

Typically in Florida, stormwater ponds are constructed as a technique for reducing nutrient loads to various lakes, rivers and estuaries. These ponds are intended to improve water quality in downstream waters by intercepting stormwater and/or groundwater inflows, and then sequestering pollutant loads prior to discharge of waters out of the ponds. The scientific basis for assumed nutrient removal rates for various stormwater treatment systems is well-established in Florida, with summary reports from dozens of studies used to guide resource management actions [3].

Based on the results of expectations of nutrient removal rates, the cost effectiveness of stormwater treatment systems can be considered in terms of the cost of the construction of such facilities, which can vary due to factors such as the cost of land, issues with constructability, etc.. On average, stormwater treatment facilities are expected to be able to perform their functions for at least 20 years and so cost-efficiencies are often calculated based on an estimated one-time capital cost, coupled with expectations of effectiveness over a 20-year period. For projects being considered for construction in 2017 (Table 2), the cost to remove a kg of nitrogen or phosphorus over a period of 20 years is expected to be \$4,112 per year per kg of nitrogen, and \$20,376 per year per kg of phosphorus.

In comparison, the physical removal of *Chara* from the lake and waterway, conducted between November 2015 and January 2016, cost approximately \$70,000 (USD). As outlined above, it would appear that physical harvesting of *Chara* removed 54.9 and 8.2 kg of nitrogen and phosphorus, respectively. For that single year, the unit cost to remove nitrogen and phosphorus calculates to \$1,275 per kg nitrogen and \$8,536 per kg of phosphorus. These values would suggest that physical removal of *Chara* is a more cost-effective technique for nutrient removal than the typical first year performance of stormwater ponds, which cost 3.2 to 2.4 times as much (per unit weight) for nitrogen and phosphorus removal, respectively. However, stormwater ponds are expected to remove nutrient loads from stormwater runoff for 20 years, with a one-time cost of construction, while the reduction in nutrient loads via the physical removal of *Chara* only occurs for the year where the removal takes place. Consequently, if physical harvesting of *Chara* was conducted more than two to three times in a 20 year period, any advantage in terms of cost would be offset, and the stormwater pond would then be the more cost-effective strategy to reduce nutrient content in surface waters. While these findings might indicate that physical harvesting of *Chara* is not a cost-effective approach to nutrient management, an alternative interpretation would be that for waterbodies with problematic abundance of aquatic vegetation such as *Chara*, a management approach that includes an initial or perhaps semi-regular (i.e., every few years) physical harvesting of plant biomass can be very cost-effective. However, over the longer term, stormwater ponds are likely to be more cost-effective for reducing nutrient impacts to waterways.

## 5. Conclusion

In the Sunshine Lake/Sunrise Waterway System, ongoing enrichment from a phosphorus-rich geology had previously resulted in the formation of a large mat of nuisance cyanobacteria, which degraded the ecology and aesthetics of the lake to the point that millions of dollars were spent to dredge the algal mat out of the system. Since the dredging project was completed, the cyanobacteria mat has not recurred. However, a chlorophyte of the genus *Chara*, otherwise known as musk grass, had become established in 2015. The establishment of *Chara* in the lake and waterway became a concern to lakeside property owners, as it soon grew to problematic levels. In response, management actions involving physical harvesting of plants and biological control (i.e., the addition of herbivorous triploid grass carp) have substantially reduced the abundance of *Chara* in the lake.

While other factors may have played a role, it appears that the physical harvesting of *Chara* was responsible for removing more than 40 percent of the annual load of nitrogen and phosphorus coming into the lake and waterway. On a one-time basis, the physical removal of *Chara* represents a nutrient reduction strategy that is more cost-effective than would be expected from a single year’s operation of a typical stormwater treatment project. However, stormwater treatment ponds are expected to perform their functions over many years; while if physical harvesting was needed more than two or three times, the advantage in cost-effectiveness of physical harvesting is lost.

Rather than considering cost efficiencies alone, the physical removal of nuisance levels of aquatic macrophytes should be considered in context of the likely response of lakes to the typical approach to their management, the use of chemical herbicides to bring about their demise. Herbicide applications have been successful at temporarily controlling infestations of nuisance aquatic vegetation worldwide. However, the plant organic material is generally left in place to degrade and decompose within the waterbody, eventually resulting in a release of nutrients back into the water column. In another waterbody in Southwest Florida (USA), large-scale herbicide treatments of nuisance aquatic vegetation have been correlated with elevated phytoplankton production in the lake, ostensibly related to the influx of nutrients associated with decaying plant material [4]. These findings are consistent with a larger examination of water quality in lakes in Florida, where it was determined that nutrient release following large-scale herbicide applications on nuisance aquatic plants was an important stressor to water quality [5]. Rather than seeking to eliminate all the *Chara* in the lake and waterway, it was recommended that a baseline level of biomass be left behind. In Southwest Florida, lakes with levels of aquatic vegetation lower than 20 or 30 percent are more likely to have problems with phytoplankton blooms than lakes with higher coverage of aquatic plants [6-8].

The complete elimination of *Chara* could thus cause other problems to emerge, just as the excessive application of herbicides could also impact water quality not only in the lake and waterway, but also in Charlotte Harbor, the estuary into which waters discharged from the lake and waterway eventually flow. In a broader context, the nutrient content removed from the lake and waterway by the physical harvesting of *Chara* biomass represents a nutrient load removed from the Harbor itself, although the nutrient load reduction represents less than 1/100th of one percent of the overall nutrient load entering Charlotte Harbor from its 8,700 square kilometer watershed [9].

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