AN ECOLOGICAL ASSESSMENT OF STAR LAKE

MOUNT HOLLY, VERMONT

Prepared for the Mount Holly Conservation Trust

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1. Introduction

Arrowwood Environmental (AE) was retained by the Mount Holly Conservation Trust to perform an ecological assessment of Star Lake. Information from the ecological assessment will be used to understand the lake system and guide potential management. This assessment is divided into six sections: 1) Star Lake Watershed; 2) Star Lake Classification; 3) Lake Sediments; 4) Aquatic Vegetation; 4) Lake Succession/Terrestrialization; 5) Wildlife; and 6) Management Options.

2. Star Lake Watershed

The watershed of a lake consists of all the lands surrounding the lake that contribute to the water inputs. Star Lake is a 62-acre lake with a watershed of 701 acres and is shown in Figure 1. Three unnamed tributary streams enter Star Lake; two on the eastern side of the lake and one on the western side of the lake. The outlet is in the southwest corner of the lake where the dam is located. Water flows from Star Lake into an unnamed tributary of Mill River, which eventually flows into Otter Creek.

The nature and condition of a watershed can have significant impacts on lake water quality in several ways. First, the amount, type and condition of the roads and other impervious surfaces in the watershed impact the dynamics of water flow into the lake. Second, the nature of the surface water inputs and the landuse surrounding these surface waters impact water quality. Third, the nature of the shorelines of the lake impact water quality and lake health. All of these factors play a key role in nutrient content of the lake, sediment inputs, and the amount of other pollutants in the lake.

The Vermont Lakes and Ponds Program has conducted an analysis of these three factors for all of the lakes in the state (Vermont Department of Environmental Conservation, 2024). According to this study, within 250' of the shoreline of Star Lake, impervious surfaces comprise 3.7% of the landuse. Given the proximity of the lake to the village of Belmont roads and buildings around the lake comprise most of this impervious cover. Though formal studies have not been conducted, given the low percentage of impervious surfaces directly around the lake, it is unlikely that these are sources of significant pollution or water quality problems for the lake.

As part of their study, the Vermont Lakes and Ponds Program also looked at land use within 100' along each of the tributaries of the lake. Natural wetlands and forested uplands comprise 96% of the land use in these areas, with the remaining 4% in agricultural lands and impervious surfaces. These numbers illustrate that Star Lake sits in a largely natural landscape. The majority of the watershed consists of wetlands and forests, while a small percentage is comprised of agricultural lands and impervious surfaces. However, the nature of

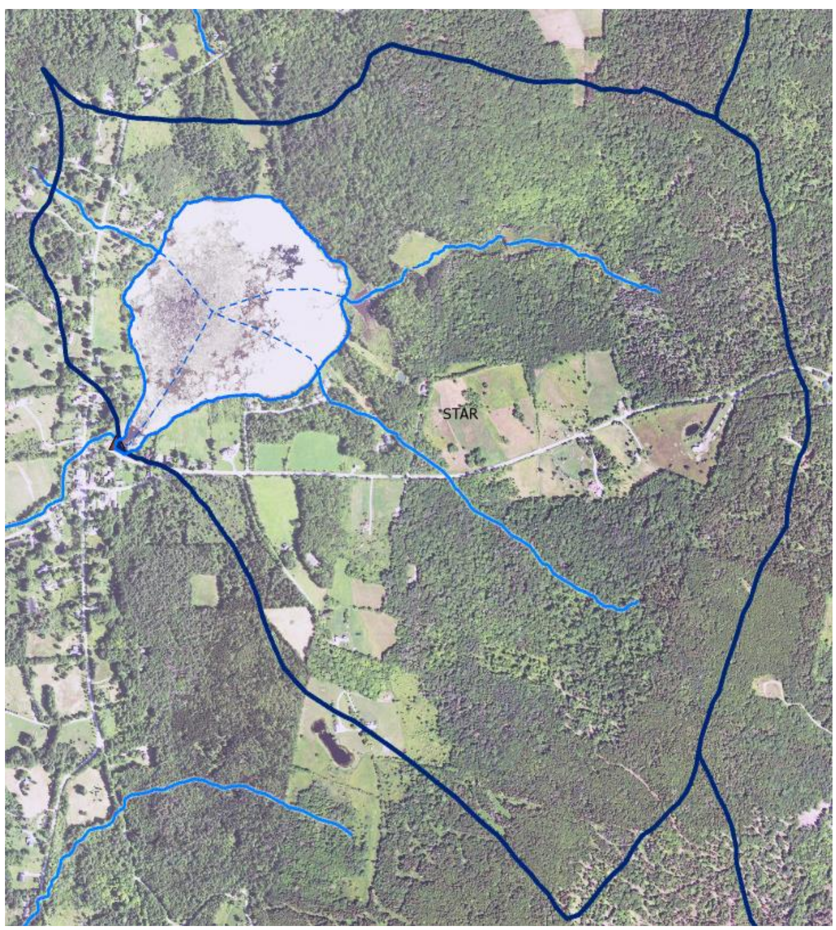


Figure 1. Watershed of Star Lake

agricultural lands can have an out-sized impact on water quality. Cultivated lands that are adjacent to surface waters, for example, can have significant impacts on water quality due to the potential for sedimentation and nutrient inputs. Most of the agricultural lands in the Star Lake watershed, however, consist of hay and pasture, which generally have more stable soils and less potential for water quality issues. It is unknown how much historic agricultural practices in the watershed have impacted water quality in the lake. In some cases, these impacts can be long-lasting, as phosphorus accumulates in the sediment and becomes "legacy phosphorus". This legacy phosphorus can be released into the water column every year as anoxic conditions develop at the sediment-water interface. However, this occurs more often in lakes than in ponds. In shallow waterbodies such as Star Lake, it is likely that the sediment-water interface does not become anoxic. In this case any legacy phosphorous present would remain bound-up in the sediment and not become available for use by the biota.

Finally, the Vermont Lakes and Ponds Program analyzed landuse within 100' of the shoreline of the lake to determine potential impacts to water quality. This data indicates that there is 2% impervious surfaces and 11.5% agricultural/open lands and the remainder in wetlands and forests. These areas directly adjacent to the lake can have an impact on water quality, for instance if failed septic systems are present or if fertilizers are used which can wash directly into the lake.

Key Points:

- Star Lake is a 62-acre lake with a watershed of 701 acres.
- Impervious surfaces comprise only 3.7% of the land use within 250' of the shoreline of Star Lake. It is unlikely that these are sources of significant pollution or water quality problems for the lake.
- Star Lake sits in a natural landscape. Wetlands and forested uplands comprise 96% of the land use within 100' of the tributaries of the lake.
- Wetland and forests comprise 86.5% of the land use within 100' of the shoreline of Star Lake. Impervious surfaces (2%) and agricultural/open lands (11.5%) comprise the remainder and are possible sources of water quality impacts.

3. Star Lake Classification

Lakes are typically classified based on physical and chemical parameters such as depth, alkalinity, and trophic status. Small, shallow waterbodies are generally considered "ponds" and larger, deeper waterbodies are considered "lakes". Limnologists often don't like to split waterbodies up into "lake" and "pond" because there is so much variation that, in some cases, the distinction can be difficult. In addition, in common parlance, the terms "pond" and "lake" are used freely and there are many cases where lakes are called ponds and ponds are called lakes. The figure below summarizes the main differences between these two types

Depth	Shallow	Deep
Photic zone	Throughout	On Margins
Aquatic vegetation	Dense throughout	Areas without
Pelagic (deep water)	No	Present
Thermal Stratification	No	Seasonal turnover
Fish species	Warm water	Warm & cold water

Figure 2. Characteristics of ponds and lakes

of waterbodies. Given these distinctions, Star Lake falls into the "pond" category. There are no deeper pelagic areas and sunlight can reach to the bottom throughout. This means that the entire waterbody provides suitable habitat for the growth of aquatic plants. Star Lake is too shallow to allow for thermal stratification that is common in many lakes in the region.

Star Lake is a low alkalinity lake underlain by bedrock composed of granodiorite and aplite gneiss from the Ludlow Mountain formation. The underlying bedrock impacts the chemistry of the water in the lake due to the fact that Star Lake is (like most lakes) partially ground-water fed. The much of the water of Star Lake gets filtered through the bedrock before it is discharged into the lake basin. Alkalinity in a lake is typically measured as CaCO3 concentrations and is, among other things, a measure of the lake's buffering capacity. Lakes with CaCO3 levels below 20mg/l are considered low alkalinity lakes and those with less than 12.5 mg/l are generally considered "stressed" in this regard. Data from Vermont DEC indicate that CaCO3 readings for Star Lake are below this 12.5mg/l threshold. This low alkalinity means that the lake has a much reduced ability to regulate pH; acidic inputs such as acid rain, therefore, have the potential to cause significant fluctuations in pH levels. Fluctuating pH levels can have impacts on the biota in the lake because many species have specific pH ranges that they can tolerate. Everything from zoo plankton to fish and aquatic plants can be impacted, though documentation of these potential changes can be difficult and require dedicated scientific studies.

Trophic status is a way to categorize different lakes based on the amount of biologically useful nutrients in the water (phosphorus and nitrogen). Oligotrophic lakes are lakes with very low nutrients available for plant (including algae) growth. Because of this low amount of growth, plant and algae productivity is low and water clarity can be quite high. Mesotrophic lakes have a moderate degree of nutrients available for plant growth and eutrophic lakes are those with a large amount of nutrients. Eutrophic lakes can have low water clarity because of the higher degree of algae growth that is possible when nutrients such as phosphorus are plentiful. Hypereutrophic lakes are lakes that have excessive amounts of nutrients, typically from human activity. These excessive nutrients fuel explosive algae and plant growth and lead to depleted oxygen levels and decrease in biodiversity in the lake.

There are multiple ways of determining the trophic status of a lake. Since phosphorus is typically the limiting nutrient for aquatic plant growth, a common measurement is the phosphorus content of the lake during spring turn-over. Other measurements include the amount of chlorophyll-a or Secchi transparency in the water column in the summer. The chlorophyll-a metric is the amount of algal growth that is occurring. Secchi transparency is a standardized measurement of water clarity obtained by sinking a black and white disc into the water and measuring how deep it can still be seen. This water clarity measurement takes into account anything that would decrease water clarity, including algal growth, plankton growth and suspended sediments.

Table 1. Trophic status categories

Vermont Lakes and Ponds Program has collected spring phosphorus data on Star Lake at various times in the past 40 years. The most recent sample was from 2016, when the lake had 19.5 µg/l phosphorus. In order to evaluate a more recent sample, in April 2024 a water sample was taken from Star Lake and sent to Endyne labs for phosphorus testing. The total phosphorus level from this sample was determined to be 19.0 µg/l. The ranges of phosphorus used to categorize a lake's trophic status vary depending on the researcher or agency. Vermont Lakes and Ponds Program use ranges and categories listed in Table 1. Following these criteria, the spring phosphorus data for Star Lake results in a "mesotrophic" lake categorization. The sample taken in 2024 also indicates that the phosphorus levels in the lake are relatively static compared to the 2016 sample. There have not been significant increases in the amount of phosphorus that is available for plant growth in the lake in the last 8 years. In addition, the phosphorus levels that are present in the lake are in the middle of the mesotrophic trophic category, so the lake is not near eutrophic status.

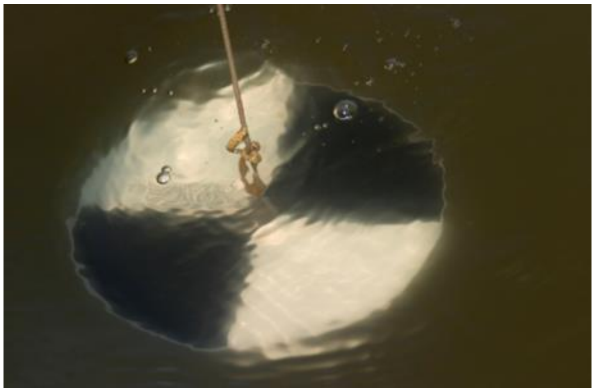


Figure 3. Secchi disk

Trophic Status	Spring Phosphorus	Secchi Depth	Chlorophyll-a
Oligotrophic	0-10 µg/l	> 5.5 meters	0 – 3.5 ug/l
Mesotrophic	10-30 µg/l	3 – 5.5 meters	3.5 – 7 µg/l
Eutrophic	30-100 µg/l	0 – 3 meters	7 – 100 µg/l
Hypereutrophic	> 100 µg/l	0 – 3 meters	> 100 µg/l

The measurement of chlorophyll-a in lakes can be highly variable depending on when the water samples are taken, recent weather conditions, and the particular growth patterns of the algae present. The most recent measurement on chlorophyll-a for Star Lake was in 1994 and averaged 3.5 µg/l. Measurements from previous years were in the 12-30 µg/l range. The amount of algal growth in the lake based on chlorophyll-a measurements was trending from mesotrophic to eutrophic status up to 1994. Though we do not have recent data on cholorophyll-a, visual observation during the field work supports this categorization of the lake.

A final metric used for determining a lake's trophic status is water clarity measured by Secchi transparency depth. As can be seen from the trophic categories in Table 1, oligotrophic lakes have the highest water clarity and hyper/eutrophic lakes have the lowest. Secchi depth readings taken in July of 2024 in Star Lake averaged 1.15 meters. The water clarity of the lake is therefore within the category of eutrophic/hypereutrophic status. This measure of water clarity does not distinguish between the factors that can inhibit water clarity. The low water clarity seen in Star Lake is the result of the shallow nature of the lake. In shallow waterbodies such as this, the lake never stratifies and there is constant mixing of the lake sediments into the water column. This mixing results in low overall water clarity.

Key Points:

- Star Lake is technically a pond.
- Star Lake is a mesotrophic lake as measured by spring Phosphorus levels which have been level over time. It does not appear that an increase in nutrients is driving the abundant aquatic vegetation growth in the lake (discussion below).
- Star Lake resembles a mesotrophic-eutrophic lake by other measures, such as Secchi transparency depth and chlorophyll-a levels.

4. Lake Sediments

The development of lake sediments is closely tied to physical and biological characteristics of the lake. Lake origin, underlying bedrock, lake size and depth, lake bathymetry, surface water inputs, vegetation, and sedimentation rates all influence the nature and distribution of sediments in lakes and ponds. In order to gain a better understanding of the lake sediments in Star Lake, sediment probe data was collected at 36 point locations throughout the lake. In addition, visual notes were taken on sediment composition and distribution.

The majority of the sediment in Star Lake consists of organic matter. Organic sediments are organized into three categories by the degree of decomposition that has occurred.

Most of the organic material found in Star Lake is considered sapric peat. The source of the buildup of organic sediments in the lake is the abundant aquatic vegetation that is present. As this vegetation senesces each year, more and more organic matter is added to the lake system. Since anaerobic conditions are (mostly) present at the sediment-water interface, decomposition is limited, and organic matter accumulates. This is discussed in more detail in Section 5.

Fibric peat is organic matter that is only partially decomposed, and the fibers of the plant material are still present and sometimes identifiable.

Hemic peat is organic material that is partially decomposed and is intermediate between fibric and sapric peat.

Sapric peat (also known as muck) is a highly decomposed organic material that contains very little plant fibers but is high in humic acid.

Coarser sediments (boulders, cobble, gravel) are more typically found along the shores of a lake and finer sediments in deeper areas. This is the result of natural wave action suspending the finer sediments in shallow areas where the wave impacts the lake bottom. These finer sediments are then washed out to deeper areas where they settle. In Star Lake, this process is not as pronounced due to the shallow nature of the entire lake and the dense floating-leaved vegetation that is present (which inhibits wave activity). However, this process is still evident in select areas. Exposed rock as well as rock substrate covered by only a few inches of organic matter occur along the northern shore. Narrow bands of gravel substrate overtopped by an organic layer are also present in areas just a few feet from shore.

The depth of the organic layer varies by location but generally increases proportional to the water depth in the lake. Near shore, the organic layer may be only a few inches deep over gravel or rock. As water depth increases, this organic layer gets thicker and thicker. Approximately 20 feet from shore, in about 1 foot of water the organic layer is 1 foot deep; approximately 75-120 feet from the shore in about 2 feet of water, the depth is 2 feet. In deeper areas further from shore, the depth of organic matter exceeded the extent of the sediment probe and was greater than 4' deep. Maximum depths of 8' of organic matter were recorded.

A layer of hemic peat was documented above the more well-decomposed muck in portions of the northern lake. This was the result of a remnant of a floating peat island that occurs in this area of the lake. The cattails along the northern shore are growing on a floating mat of hemic peat. These mats can move around in open water and sometimes break apart. Unexpectedly, areas of hemic peat (including abundant fragments of woody material) were documented beneath the deep layer of muck. Both their abundance and their location below deep layers of muck suggests that these woody fragments are relics of the forest that was present before the basin was flooded to create the mill pond.

The typical pattern of coarser substrates along the margins and finer substates in deeper areas can also be interrupted by surface water inputs. Fast-flowing surface waters transporting suspended coarser sediments lose velocity when reaching the lake, dropping the sediments out of suspension, and creating shallow deltas. This phenomenon is evident at the stream inlets on the east side of the lake. Flood level storm events can create large influxes of sediment, especially if stream banks and land use along the inlet streams are susceptible to erosion. The beaver dam complex at the northeastern end of the lake can act as a sink for eroded sediment, but if the beaver dam breaches that stored sediment can wash into the lake.

Large scale sedimentation events result in continual shallowing of the lake, particularly in the delta areas. Depending on the frequency of flooding and sedimentation, this can result in areas that were once aquatic habitats developing into wetland habitats. As climate change increases the frequency and intensity of flooding events, these impacts are likely to be accelerated.

Key Points:

- Abundant aquatic vegetation is the ongoing source of the muck accumulation in the lake.
- Narrow bands of coarser sediments along the shore are quickly overtopped by sapric peat (muck).
- Sapric peat depths in the lake exceed 4 feet in most places, and depths of 8 feet have been recorded.
- A layer of less-decomposed hemic peat consisting of woody fragments is present beneath the muck layer; a relic of the forest that was present prior to flooding the basin.
- Sedimentation in the areas near the stream inlets creates shallow deltas and can create conditions where aquatic habitats transition to wetland habitats.

5. Aquatic Vegetation

A list of all aquatic plant species encountered during the inventory was compiled during the field work and presented in Table 3. Plants that are non-native species are shaded green. This table includes information on the plant type.

Table 3 also includes information on the S-rank of rare and uncommon species. Determination of how rare or common a particular species is in the state is based on rarity rankings (Table 2) assigned to each species by The Vermont Natural Heritage Inventory (NHI) which maintains a list of species that are rare, threatened and endangered in the state. This methodology was used in Star Lake to determine if any of the species documented in the lake were considered rare or uncommon.

Table 2. Plant rarity ranking

S-rank	Description
S1	Very Rare
S2	Rare
S3	Uncommon
S4	Common
S5	Common and widespread

Two species that are uncommon or rare were documented in Star Lake during the current inventory. Stiff arrowhead (*Sagittaria rigida*) is an emergent species with arrow-shaped leaves that is found throughout the state, though is uncommon (S3-ranked). It is similar to the more abundant common arrowhead (*S. latifolia*) and can only be distinguished when the plants are in flower or fruit. Only a few individuals of the stiff arrowhead were documented in the lake, along the northern shore.

"Aquatic" plants are plants that are typically found in lake and pond environments and includes submerged vegetation or floating-leaved vegetation

"Emergent" plants are those that occur on the margins and shallow areas of lakes and ponds or in deep-water wetlands; these are more transitional habitats between truly aquatic lake habitats and more terrestrial wetland habitats.

"Wetland" plants typically occur on the wet shores of lakes or in wetlands not associated with lake systems.

Table 3. List of plant species

Latin Name	Common Name	S-Rank*	Plant Type
Acer rubrum	red maple		Wetland
Alnus incana	gray alder		Wetland
Bidens vulgata	tall beggar's-ticks		Wetland
Brasenia schreberi	water shield		Aquatic
Calla palustris	water-arum		Wetland
Carex lasiocarpa	hairy-fruited sedge		Wetland
Carex stricta	tussock sedge		Wetland
Ceratophyllum demersum	coontail		Aquatic
Ceratophyllum echinatum	hornwort	S2S3	Aquatic
Chamaedaphne calyculata	leatherleaf		Wetland
Cicuta bulbifera	bulbiferous water-hemlock		Wetland
Comarum palustre	marsh cinquefoil		Emergent
Cornus racemosa	gray dogwood		Wetland
Cornus sericea	red-osier dogwood		Wetland
Eleocharis acicularis	needle spike-rush		Aquatic
Eleocharis palustris	marsh spike-rush		Emergent
Equisetum fluviatile	water horsetail		Emergent
Fontinalis sp.	moss		Aquatic
Glyceria canadensis	rattlesnake grass		Wetland
Ilex verticillata	winterberry		Wetland
Iris pseudacorus	Siberian iris		Wetland
Iris versicolor	blue flag		Wetland
Juncus effusus	soft rush		Wetland
Ludwigia palustris	common water-purslane		Wetland
Lycopus uniflorus	common water-horehound		Wetland
Lysimachia terrestris	swamp-candles		Wetland
Lythrum salicaria	purple loosestrife		Wetland
Myosotis scorpioides	common forget-me-not		Wetland
Nuphar variegata	common yellow pond-lily		Aquatic
Nymphaea odorata	waterlily		Aquatic
Phragmites australis	common reed		Wetland
Potamogeton crispus	curly pondweed		Aquatic
Potamogeton robbinsii	Robbins' pondweed		Aquatic
Sagittaria latifolia	common arrowhead		Emergent
Sagittaria rigida	stiff arrowhead	S3	Emergent
Schoenoplectus tabernaemontani	common bulrush		Emergent
Scirpus cyperinus	wool-grass		Wetland
Scirpus microcarpus	barberpole bulrush		Wetland
Scutellaria galericulata	marsh skullcap		Wetland
Sparganium emersum	green bur-reed		Emergent
Sparganium eurycarpum	large bur-reed		Emergent
Spirodela polyrrhiza	greater duckweed		Aquatic
Symphyotrichum puniceum	red-stemmed aster		Wetland
Triadenum fraseri	Fraser's marsh St. John's-wort		Wetland
Typha latifolia	broad-leaved cattail		Wetland
Utricularia macrorrhiza	common bladderwort		Aquatic

** Plants with no S-rank shown are S4 or S5*

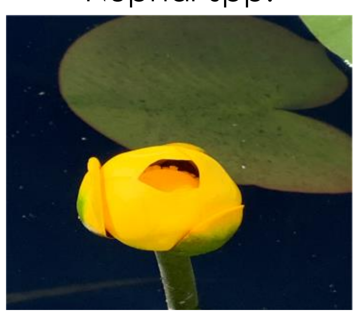
Figure 4. Hornwort

Hornwort (*Ceratophyllum echinatum*) is a submerged aquatic plant that is uncommon to rare in Vermont (S2S3-ranked). This species was found throughout the lake in low abundance, though in small areas it was moderately abundant. Coontail (*C. demersum*) is a closely related very common species that is abundant throughout the lake.

The dominant component of the aquatic vegetation in Star Lake is comprised of floating-leaved plants. Three species make up this floating-leaved layer: white water lily, pond lily, and water shield. Together, these species can form a dense layer covering the water's surface.

Water Lily
Nymphaea spp.

Pond Lily
Nuphar spp.



Water Shield
Brasenia sp.

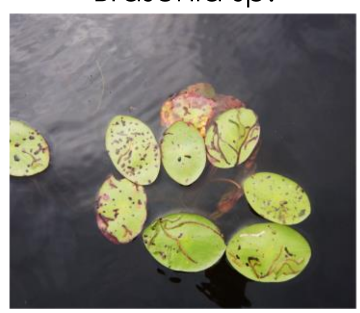


Figure 5. Dominant floating-leaved species in Star Lake

The most common of the floating-leaved species is white water lily, which is the dominant plant found throughout the lake. Water shield is also found throughout the lake but is less abundant than water lily. Pond lily, with its more rounded leaf bases and yellow flowers, is most abundant on the eastern shore, though can be found in scattered locations throughout the lake.

The most common submerged aquatic species in the lake are coontail, common bladderwort and curly pondweed. The first two species comprise most of the submerged aquatic flora in the lake (see below for discussion of curly

Figure 6. Coontail (left) and bladderwort (right)

pondweed). The overall diversity of aquatic species in the lake is quite low.

Though sexual reproduction is important for the survival (and continued evolution) of the floating-leaved species, most of the spread of water lily occurs via asexual reproduction. Growing beneath the sediment at the base of these plants is a large underground stem called a rhizome. This rhizome grows horizontally through the sediment and readily sprouts new stems. In order to support this structure, significant amounts of energy in the form of starch need to be allocated to the rhizomes. The rhizomes are the reason that floating-leaved species are able to spread so rapidly in areas that have suitable habitat like Star Lake. Removal of the leaves and stems does little in terms of overall plant control since new leaves can readily sprout from the rhizome.

This large starchy organ has not gone unnoticed by wildlife; it is commonly eaten by beavers and is the main source of food for muskrats. When moose wade into the shallows of a pond, they are doing so to feed on rhizomes, which can constitute the main source of their summer diet. In many cases, beavers and

Figure 7. Rhizome of water lily

muskrat will dislodge the rhizomes while feeding; which then float to the surface and have the appearance of small logs or baseball bats.

Dense canopies of floating-leaved species like water lily have been shown to have mixed impacts on the lake ecosystem. The presence of floating-leaved species can have a positive impact on fish and invertebrate communities in the lake. However, these positive impacts have been shown to decline once the threshold of approximately 40% cover of floating-leaved species is exceeded (Wiley, Met al. 1984). Some researchers have reported reduced dissolved oxygen concentrations beneath the canopies due to less wave activity and mixing with air (Moore et al. 1984; Frodge, Thomas, and Pauley 1990).

A. Vegetation change over time

The abundance of floating-leaved vegetation in the lake has increased substantially in the past decade. This is illustrated in Figure 8 which shows the progression of aquatic vegetation coverage over a twenty year period. The imagery includes both floating-leaved aquatic vegetation as well as submerged aquatic vegetation that grows to the surface of the lake. This imagery was taken a different times during the year, ranging from July – August, so should only be used as an approximation. The year 2003 image shows little coverage, mostly in the northeastern corner of the lake. Five years later in 2008, abundant floating leaf vegetation is evident. In 2011, however, much less coverage is apparent, and may be from vegetation management. In 2016, coverage is nearly complete in the northern part of the lake and in 2024, the margins of the lake show complete coverage, and the center of the lake shows near-complete coverage.

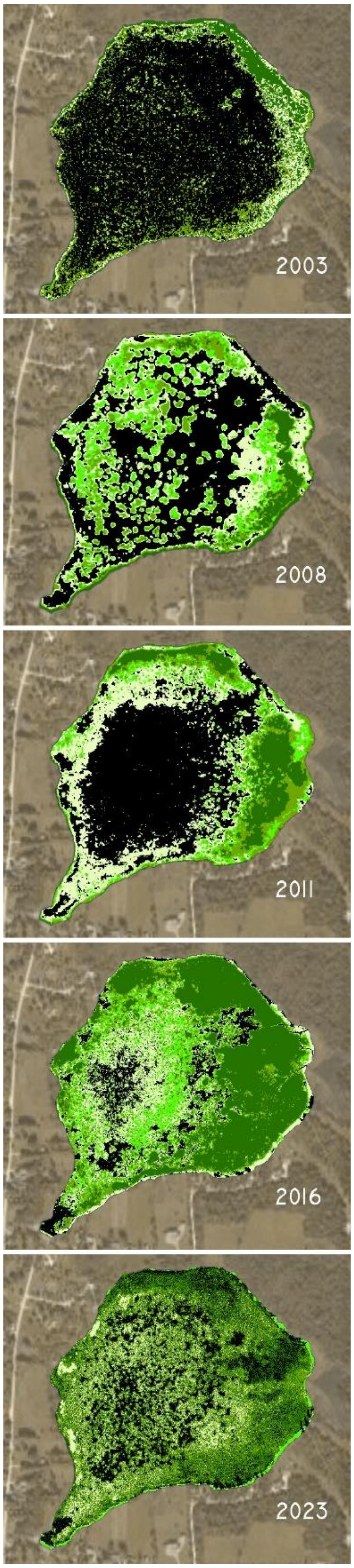


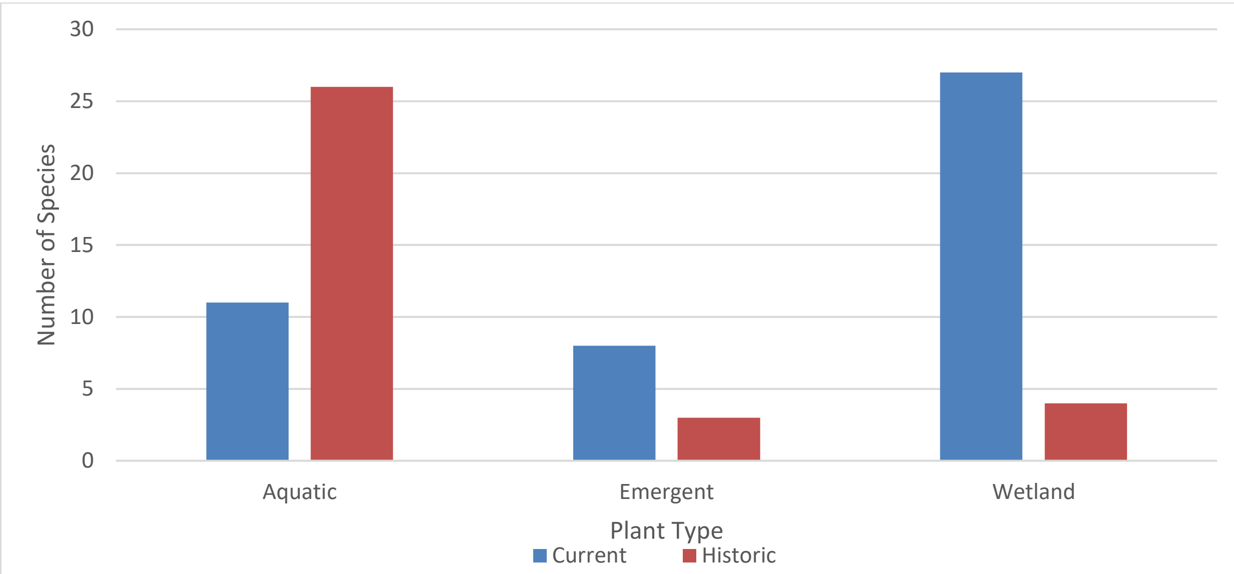
Figure 8. Vegetation change over time

In order to further compare the change in vegetation of Star Lake over time, previous species lists compiled by the Vermont Lakes and Ponds Program were analyzed. The Vermont Lakes and Ponds Program conducted various plant inventories from 1985 to 2010. A total of 32 species were documented during those inventories. By contrast, a total of 46 species were documented during the current inventory.

Each species documented historically was also categorized by plant type as described above. This categorization allows a more detailed analysis of plant diversity in the lake. Figure 9 illustrates that the number of aquatic plants in the lake has decreased, while the number of wetland plants has increased substantially.

The increase in the number of wetland plants could be the result of a difference in survey methodology, a change in the plants present, or a combination of the two. While wetland-type plants are included in the Vermont Lakes and Ponds Program plant lists, the focus of the inventories were typically on aquatic plants, and it is unknown how much attention was on inventorying the wetland plants growing on the margin of the lake. The increase in wetland plants shown in Figure 9 could also be a result of more wetland-type habitats present on the shores of the lake. This occurs as the lake becomes shallower and the near-shore areas that represent the transition between the aquatic and wetland habitats becomes wider. In these cases, wetland-type plants become more dominant along with emergent-type plants.

Figure 9. Change in Plant Type



The observed decrease in the diversity of aquatic plant species is likely the direct result of the proliferation of the floating-leaved species. The shade created by dense floating-leaved vegetation has significant impacts on aquatic plant communities. Since only a few submerged aquatic plant species can tolerate the low light conditions beneath the complete "canopy" of water lily leaves, diversity of submerged species decrease, including native submerged species. In 2010, for example, the most abundant nuisance aquatic species was large-leaved pondweed (*Potamogeton amplifolius*). This native submerged species appears to have been out-competed by the floating-leaved species and is no longer present in the lake.

B. Aquatic Non-native Invasive Species (NNIS)

As shown in Table 3, four non-native invasive species were documented during the current inventory: Siberian iris, purple loosestrife, common reed, and curly pondweed. Siberian iris, purple loosestrife and common reed are all wetland plants that were documented along the shore of the lake. Curly pondweed is the only aquatic NNIS documented in the lake. Eurasian watermilfoil had been previously known from the lake but was not documented during the current inventory.

Curly pondweed is native to Eurasia and has been well-established in the region since the early 1900s. It reaches its greatest abundance early in the growing season (July) and by late summer may be mostly senesced. While it can reproduce by sexual reproduction via seed, the most common way that it spreads is via fragmentation and the production of turions. Turions are winter buds that are formed in the summer at the tips of the plants, fall off the plant and settle in the sediment. These turions then sprout and grow a new plant in late winter or early spring.

Figure 10. Sprouting turion of curly pondweed

This species is very abundant in the southern end of Star Lake around the swimming beach and the lake outlet and comprises most of the biomass annually hand-harvested from these areas. It is also present in the rest of the lake but most abundant where floating-leaved cover is minimal. This species is largely absent from the lake in the late summer, at which time the aquatic vegetation is dominated by native species.

The other invasive species present in the lake are found mostly around the margins of the lake and along the lake shores. Siberian iris and purple loosestrife in particular are plants that do not typically grow in standing water. Given the relatively low numbers of individuals of each of these species present, the best control method is manual removal. In order to fully remove these plants from the shore, they should be dug up to remove the crown so that they cannot regrow.

The patch of common reed documented on the northern shore of the lake is a 10'x 6' area with 75% cover. Unlike the Siberian iris and purple loosestrife, common reed has the potential to invade shallow open water areas. Due to the size of this population, eradication of this infestation may be difficult. Repeated pulling and uprooting of the plants can sometimes be an effective control. Manually applying herbicide to each individual is typically an effective treatment, though an application to apply herbicide in a wetland would need to be obtained.

Key Points:

- One uncommon (stiff arrowhead) and one uncommon-rare (hornwort) plant species were documented in the lake.
- One species of NNIS (curly pondweed) is currently known from the lake and is abundant in the swimming beach and lake outlet area.
- Most of the floating-leaved vegetation is comprised of white water lily, though pond lily and water shield are also present.
- As floating-leaved species become dominant, plant diversity of aquatic species is decreasing, but diversity of emergent and wetland species is increasing.

6. Lake Succession/Terrestrialization

Succession is a term used to denote the change in natural communities over time. Succession in lake and pond ecosystems is referred to as hydrosere succession and refers to the change of an aquatic ecosystem to a terrestrial ecosystem. The term "succession" has come under scrutiny from ecologists because it implies that ecosystems are changing in a directional manner that will reach a final stable state known as a climax community. Evidence for this directional and stable state is scant, especially in complex aquatic systems. The changes seen in some aquatic communities is therefore better referred to as "terrestrialization". In general, if terrestrialization occurs, it can take many different forms and occur on a range of timescales. The textbook example consists of multiple, distinct stages. In the initial stages, open water is colonized by phytoplankton and submerged aquatic vegetation. As sediment builds up and the pond becomes shallower, floating-leaved vegetation becomes established and then dominant. In the shallowest areas along the edge of the pond emergent vegetation, such as sedges and cattails, become established. As the sediment continues to build up, appropriate habitat for the emergent vegetation expands further and further into the pond until the area becomes an emergent marsh. Further change into a shrub swamp or forested swamp can also occur.

Aquatic systems are complex systems influenced by different factors such as hydrologic inputs, water residence time, nature of outlets, size of the basin, depth, bathymetric shape of the basin, sediment type and vegetation. In many cases, the classic succession from aquatic to terrestrial ecosystem does not occur without dramatic changes to the physical structure of the lake. However, terrestrialization can occur in shallow ponds with abundant aquatic vegetation and in ponds with high rates of sediment accumulation.

Figure 11. Cattails colonizing shallow areas

Studies of lake ecosystems have shown complex interactions between aquatic macrophytes and lake sediments. In larger lakes with pelagic (deep water) areas and abundant wave action, organic sediments accumulate and then get resuspended and distributed throughout the lake. In the case of Star Lake, this resuspension and distribution does not occur. In addition, the abundant growth of vegetation in Star Lake adds organic matter to the lake ecosystem continually. The anoxic conditions beneath the water create conditions where decomposition rates are very slow. In areas where aquatic vegetation is abundant, the rates of decomposition are far exceeded by the rates of organic matter additions in the form of plant matter. This results in conditions where sediment slowly and continually builds up. Other researchers have also documented lakes where abundant growth of aquatic vegetation has led to the build-up of sediments and a shallowing of the lake (Murphy and B.H Wilkinson 1980).

In most cases, abundant aquatic plant growth enriches sediments, supplies additional sediment material and promotes the growth of more aquatic plants (Godshalk and Wetzel 1984). This process can create a positive feedback loop where the more vegetation that is present, the more the habitat becomes suitable for the growth of dense vegetation (Carpenter 1981).

In Star Lake, this positive feedback loop driven by the abundant aquatic vegetation and deep organic sediments has created conditions favorable for terrestrialization. This process can be seen spatially in areas of the lake where cattails have colonized the margins of the lake and are expanding out away from the shore.

Key Points:

- A positive feedback loop driven by abundant aquatic vegetation creates and maintains suitable habitat for the continued growth and abundance of aquatic vegetation.
- Organic sediments are accumulating in the lake due to the abundant aquatic vegetation and slow rates of decomposition in anoxic environments. This can eventually lead to the lake becoming shallower over time.
- The two above conditions allow for the slow process of terrestrialization to occur.

7. Wildlife

Wildlife in and around Star Lake is diverse and abundant. It was beyond the scope of this study to document all the wildlife that use Star Lake, but targeted sampling and incidental notes were taken on wildlife presence while conducting field work.

In order to sample the base of the food chain in the lake, plankton tow-net samples were taken in July 2024. These samples yielded an abundant and diverse zooplankton community and contained Rotifers such as *Asplanchna spp*. and *Euchlanis spp*.. Copepods such as *Cyclops spp*. and *Mesocyclops spp*., and Cladocera in the families Daphniidae and Chydoridae. This plankton community goes largely unnoticed by causal lake users; however, these diverse and abundant plankton do not go unnoticed by other species in the lake. Larger zooplankton and larval insects rely on these small zooplankton for survival. The tadpoles of frogs, eastern newts, most minnows, some young game fish and multiple species of waterfowl also prey on the abundant zooplankton community present in Star Lake.

Figure 12. Bullfrog on the margins of Star Lake

Multiple amphibians were documented during the field work, including green frogs, wood frogs, eastern newts, bullfrogs, and spring peepers. Among the reptiles, it is likely that painted turtles and snapping turtles are also found in the lake. In their different life stages, these reptiles and amphibians (together called "herps") are preyed upon by the many fish species found in the lake, including golden shiners, bullhead, catfish, pumpkinseed, rock bass and pickerel.

The herps and fish are then preyed upon by the bird and mammal species that are found in and around the lake. While no bird surveys were conducted as part of this study, the most obvious visitors included great blue heron, bald eagle, and osprey. During the July site visit, a pair of juvenile osprey were constantly flying, hunting, and playing above the lake. Beaver are an ever-present (and sometimes unwelcome) resident of the lake and have a well-established dam and lodge at the northeastern end of the lake. This area includes an array of open water ponds and channels intermixed with marsh and shrub swamp vegetation. These mosaics of varied habitats and structure have been shown to be hot-spots for wildlife diversity (Law et al. 2019; Windels 2017). Muskrat, river otter and mink have also been documented in and around Star Lake.

Situated within a largely forested upland landscape, the aquatic and wetland habitats available in and around Star Lake are host to an entirely different suite of species that would not be found in the area in its absence. From the zooplankton to the bald eagles, Star Lake provides abundant habitat for a diverse array of wildlife species.

8. Management Options

Star Lake has a history of management, from its beginnings as a mill pond to the dam restoration in 2015. Intermittent management of vegetation in Star Lake has occurred at various times in the past 25 years. Most of the management has been to control the dense aquatic (native and non-native) vegetation in the lake. This includes herbicide control for Eurasian watermilfoil, benthic barriers, hand harvesting, and mechanical harvesting.

There have been many scientific studies on the efficacy of different control methods for managing aquatic plants in different situations (Gettys et al. 2020; Gettys and Johns 2014; Helfrich 2009) and Table 4 presents an overview of some options. Unfortunately, many of the management strategies that have been developed are, for Star Lake, only "false" options. These are options that may look good in theory but are not realistic because of excessive cost, permitting restrictions or other barriers to implementation.

The state of Vermont requires an Aquatic Nuisance Control permit for performing all the management activities listed in Table 4 except hand harvesting. During the permit process, regulators often make the distinction between aquatic *invasive* species and aquatic *nuisance* species, and managers should understand the difference when considering management alternatives. Invasive species are species that are not native to the region and have become aggressive invaders which have negative impacts on native aquatic communities. Nuisance species are native species which interfere with recreational activities but do not have negative impacts on the aquatic ecosystem. In Star Lake the management of curly pondweed would be considered an aquatic *invasive* issue, while the management of floating-leaved species, an aquatic *nuisance* issue.

Table 4. Control Methods for Aquatic Vegetation

Type	Control Method	Pros	Cons
Physical Removal	Hand Harvesting	Targeted control, effective short term	Not feasible for larger areas; short term
	Mechanical Harvesting	Effective in large areas	Expensive; short term
Biological Control	Using other organisms to reduce nuisance species	Natural and non-toxic	Effectiveness highly variable
Chemical Control	Herbicide	Effective over large areas	Potential impacts on non-target organisms; difficult to permit
Habitat Alteration	Bottom Barriers	Effective for small areas	Impacts on non-target species; not feasible for larger areas
	Drain and Dredge	Effective long term	Prohibitively expensive; difficult to permit

A. Physical Removal

Physical removal of aquatic plants generally takes two forms: hand harvesting and mechanical harvesting. Hand-harvesting is an ongoing management activity at Star Lake in the vicinity of the swimming beach. This activity (along with benthic barriers) can be an effective way to control the growth of aquatic plants in this small area and allows some limited recreation to occur at the beach. Since permitting is not required, hand-harvesting can be done as necessary without outside approval. However, due to the labor-intensive nature of this control method, this is only feasible in small areas. In addition, unless each plant is uprooted, the control is typically short-lived and may need to be conducted multiple times per year.

Mechanical harvesting has been conducted on Star Lake in the past. This method has the advantage of being effective at removing vegetation over a much larger area than hand harvesting. However, like hand-harvesting, this is a short-term control option. Regrowth of aquatic vegetation typically occurs, requiring multiple harvests during a season to keep areas clear of vegetation. In addition, this option can be expensive. Due to these limitations, it is not feasible to harvest vegetation from the entire lake. However, as was conducted in the past, maintaining open lanes for navigation can have some noted benefits for lake users. These open lanes allow for users to access many parts of the lake that are otherwise very difficult to access, especially later in the summer. Controlling floating-leaved plants in these limited areas also creates habitat for other aquatic species that cannot tolerate the shade and low oxygen conditions beneath the floating-leaved canopy. Finally, there is some evidence that maintaining some more open areas may benefit fish populations (Wiley, et al. 1984).

The potential impacts on the lake community from harvesting will depend on the size of the area that is harvested and the frequency of harvesting. In general, most impacts from aquatic plant harvesting are shown on a scale when more than 50% of the vegetation in a lake is removed. This type of widespread mechanical control can have numerous impacts including shifting species dominance and providing more habitat for AIS such as curly pondweed or Eurasian watermilfoil. The control rates typically permitted in Vermont, which caps the permitted control to 40% of the littoral zone, are meant to avoid widespread impacts to aquatic vegetation. The actual impacts of control vary widely from lake to lake, which is why Vermont Lakes and Ponds Program mandates monitoring vegetation as condition of permitted control activities.

In the case of Star Lake, if control of aquatic vegetation is a management goal, the inclusion of mechanical harvesting is one of the best treatment options. It is effective at removing vegetation, even if only temporarily. It is flexible in that the treatment areas can be selected ahead of time, and it allows users access to lake later in the season when it is otherwise inaccessible. If long-term harvesting is a goal, purchase of a harvester may be the most cost-effective option. Finally, any control effort should be undertaken as part of a long-term management plan.

B. Biological Control

Biological control of aquatic vegetation in general and targeted control for specific invasive species is an ongoing area of research. There has been limited work on biological control of curly pondweed but none that has proven to be sufficiently effective. In the Pacific Northwestern United States and in areas of Africa, water lily is considered an invasive species. In these areas, work looking for biological controls for this species has had little success. There are many native insects known to feed on water lily plants, but since this is not an invasive plant species in our region, no work has been done on using these for biological control.

In the southern and midwestern United States, grass carp (*Ctenopharyngodon idella*) have been introduced into some lakes and ponds to control aquatic vegetation. This species is not native to North America and can have many negative impacts on aquatic systems, including loss of diversity, disruption of habitat for aquatic fish and invertebrates, increased turbidity and resulting increase in available nutrients in the water column (Dibble and Kovalenko

2009). For these reasons, the state of Vermont does not allow introduction of this species into Vermont waters.

C. Chemical Control

Herbicides have been used to control invasive and nuisance aquatic plants for many years. There have been some studies testing the effectiveness of glyphosate to control water lily plants. One study determined that once/year spraying was not sufficient; multiple applications per year were required to control the plants (Hofstra et al. 2013). While application of these herbicides can be effective in killing aquatic vegetation, there are negative impacts of this management approach to consider such as impacts to non-target organisms, including fish. In addition, application of herbicides into lakes in Vermont requires water-use restrictions and is often met with opposition from the surrounding community. The biggest hurdle to using herbicides in Star Lake, however, is regulatory restrictions. Currently, the state of Vermont is only permitting the use of a single herbicide in Vermont lakes: ProcellaCOR EC. This herbicide has been developed to selectively treat Eurasian watermilfoil (*Myriophyllum spicatum*). While it does have some impact on water lily plants, this impact is limited to browning of foliage, from which the plants typically recover. This herbicide does not appear to impact any pondweed (*Potamogeton spp.*) species, including curly pondweed. Because of these factors, it is unlikely that any chemical control application would be approved for treatment in Star Lake at this time (Kim Jensen, personal communication 1/13/25).

D. Habitat Alteration

The installation of benthic barriers to control aquatic plants has occurred in Star Lake for many years. The barriers are an effective means of controlling aquatic plant growth because they alter the habitat such that no plants can grow through the barrier. While this is an effective method where they are applied, they can only be feasibly used in small areas. These barriers have been successfully installed in the swimming area to allow for recreational activity to occur.

In order to control nuisance vegetation lake-wide, large-scale habitat alteration such as draw-down has been conducted in some small lakes and ponds. A prolonged draw-down has the effect of initiating widespread decomposition of built up organic sediments as they are exposed to oxygen. It can also result in desiccation of the seed bank present in the sediments. Draw-downs are sometimes paired with sediment dredging. Dredging can offer a longer-term solution to excessive aquatic plant growth because of the removal of the sediment, seedbank, and rhizome material from which plant growth occurs. Like a prolonged drawdown, however, draw-downs and dredging remove non-target organisms and all life, drastically altering the very nature of the aquatic ecosystem. Large-scale habitat alteration techniques, while effective, are typically only used on small ponds due to their excessive cost. Obtaining community support, regulatory permits, and funding for such an undertaking on a lake the size of Star Lake is not feasible.

Key Points:

- The ecological processes at work in Star Lake have resulted in an aquatic ecosystem that is not compatible with recreational uses such as motorboating.
- Chemical control of aquatic vegetation in Star Lake is not feasible because of efficacy of treatments and permitting restrictions.
- Dense aquatic vegetation can be managed by benthic barriers and hand-pulling in small areas.
- For larger areas, dense aquatic vegetation can be managed by mechanical harvesting.

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