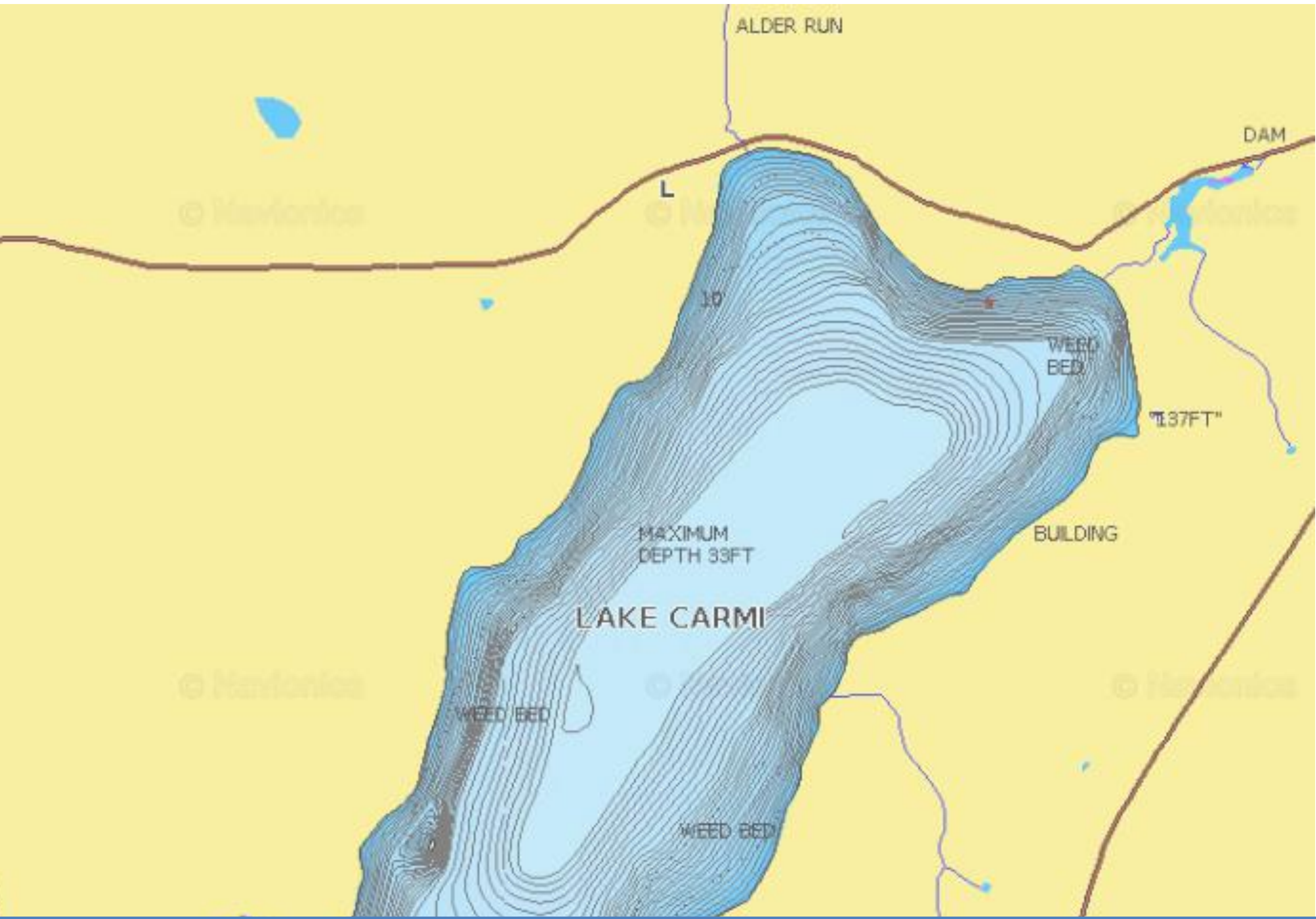

LAKE CARMI AQUATIC MACROPHYTE SURVEY 2018

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Report Submitted to the Vermont Department of Environmental Conservation

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1. Introduction

In 2018, Arrowwood Environmental (AE) was retained by the Vermont Department of Environmental Conservation (DEC) to conduct an inventory of aquatic macrophytes in Lake Carmi, Vermont. As part of the Lake Carmi Action Plan, Vermont DEC is working towards preventing cyanobacteria blooms in the lake by decreasing phosphorus loading during summer lake stratification. The focus of the current project is to conduct an inventory of aquatic macrophytes to serve as baseline data as the aeration system is implemented and management of the lake moves forward.

Lake Carmi is a 1402 acre lake located in the town of Franklin in Franklin County, Vermont. It is underlain by the Fairfield Pond bedrock formation which consists of metasedimentary phyllites. The underlying bedrock can impact the chemistry of the water, in this case resulting in a moderate-alkalinity lake.

The watershed of Lake Carmi is 7150 acres in size and consists of a mixture of active agricultural lands, forestlands and residential rural development. This rural development includes numerous residential dwellings and "camps" along the shores of the lake. On the eastern shore, Marsh Brook flows into the lake as well as five other smaller drainages. Similarly, the south and western shore has five small drainages which feed the lake. On the northern shore, Alder Brook and one other smaller drainage flows into the lake. The outlet is located on the northeastern shore where a dam controls the water level. After flowing through Mill Pond, water that leaves Lake Carmi flows into the Pike River and north into Quebec and Missisquoi Bay of Lake Champlain.

Based on data collected in Lake Carmi since 1979, this waterbody appears to be a stable eutrophic system with high phosphorus levels (mean summer TP 31ug/l) and low water transparency (secchi depth average 2.1 m) (Vermont Agency of Natural Resources 2018).

2. Methods

The study area for the inventory was obtained from Vermont DEC. Prior to the inventory, Vermont DEC conducted a bathymetric survey of the lake and provided that data to AE. Based on that data and the data from secchi disk depths, DEC also provided AE with a littoral zone, which consisted of all areas of the lake less than 14 feet deep. This littoral zone comprised the boundaries of the aquatic inventory.

Prior to field work, aerial ortho imagery of the lake was analyzed. This included various imagery from the 1990s up to 2016 and included black and white as well as full color and color-infrared imagery. The purpose of this analysis was to create a preliminary base map of aquatic vegetation in the lake. The most easily observed vegetation is the Water Lily Aquatic Community because this vegetation is readily visible on the surface of the water. Algal blooms often prevented the delineation of milfoil beds or other surfacing emergent aquatic vegetation. Though this preliminary map was significantly revised during the field work, it provided a valuable base map as well as insight into the seasonal variations present in some of the aquatic vegetation.

Three days of field work were conducted in 2018 on August 15, 16 and 30 by Michael Lew-Smith. During the field work, the littoral zone was circumnavigated with a motor boat or a kayak. The motor boat was used for the majority of the inventory while the kayak was used to inventory shallow areas. Data was taken using a Trimble Juno GPS unit with custom data entry forms so that all data collected is linked to a specific geographic location. Narrative data not entered into the digital data forms was recorded in a field notebook.

Two different survey methodologies were employed to document and map the aquatic species in the lake, the Grid-Point Survey based on the methods from (Hauxwell et al. 2010) and a Qualitative Survey based on methods from the Vermont Agency of Natural Resources Department of Environmental Conservation (2006) field manual. Each of these techniques is outlined below.

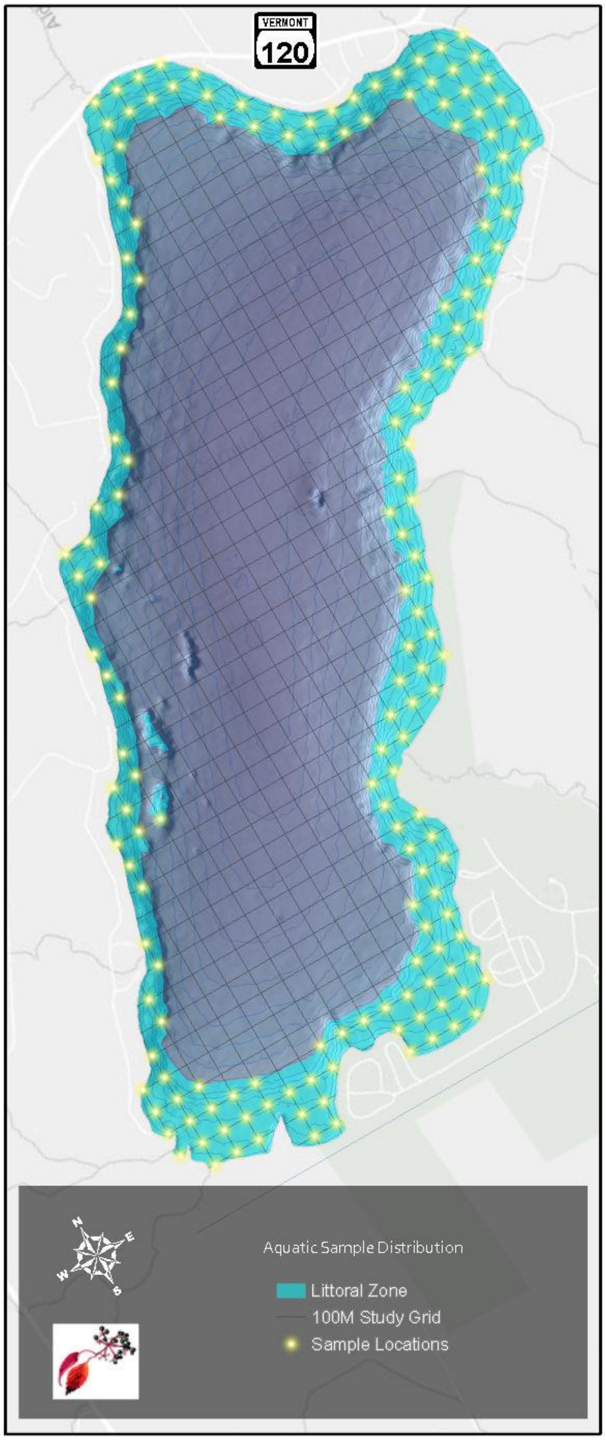

Figure 1. Study Area and Grid Point Sampling Locations

a. Grid Point Sampling

The purpose of the grid-point sampling is to ensure that all areas of the lake receive a standardized vegetation sample which is reproducible. This sampling technique also aids in the mapping of native and invasive aquatic vegetation. A grid of 577 points located 100 meters apart was developed by DEC and provided to AE for use in the survey. Based on conversations with DEC staff, the grid points were clipped to the previously established littoral zone. This resulted in a total of 172 grid points for sampling as shown in Figure 1. The lake boundaries, littoral zone and grid point locations and preliminary vegetation mapping were uploaded to a Trimble Juno 3B GPS unit, which was used to navigate to each point on the lake using a motor boat or kayak. An aquatic survey rake was used to take a vegetation sample at each point location. In waters shallower than 10’, a rake on a pole was used to sample vegetation. In waters deeper than 10’, a survey rake attached to a rope was used to sample vegetation. Rake fullness, as outlined in Table 1 was recorded for each sample to obtain information about vegetation density (Hauxwell et al., 2010). Each aquatic plant on the rake was identified to species. In addition, data on the percent cover of native vegetation and community type was taken, when visible. A view-scope was used to view the vegetation when necessary. Presence and abundance of aquatic invasive species (AIS) was also documented at each point. All data was recorded using a digital data form on the GPS unit.

Table 1. Vegetation Abundance Categories for Point Intercept Sampling

Rake Category	Abundance
None	No plants present on rake
Single	A single plant present on rake
Low	Sparse vegetation present on rake
Medium	Moderate amount of vegetation on rake, typically enough to cover center of the rake but not the tines
High	Large amount of vegetation on rake, typically enough to cover the rake tines

b. Qualitative Sampling

The Qualitative Method is based on the Vermont Agency of Natural Resources Department of Environmental Conservation (2006) field manual technique and is used as a complement to the grid-point sampling. This method is often used to supplement grid-point sampling because it is a better technique for detecting rare species and the boundaries of vegetation types. Limited field time, however, prevented employing this method for the entire lake. Instead, this method was used to gain additional information on aquatic macrophytes in between grid points and in certain focus areas. These focus areas included areas of Eurasian water milfoil (EWM) infestation, boundaries of native aquatic communities and representative examples of each of the vegetation communities. During this qualitative sampling, the aquatic vegetation was viewed from the boat or with a view-scope and notes on species composition, presence and abundance of EWM, and percent cover of native vegetation was recorded as appropriate. Areas of EWM, in particular, were circumnavigated and GPS points were taken at the boundaries of the infestation in order to map the extent of this invasive species. Visibility through the water column during the inventory was poor. This limited the amount of qualitative data that could be obtained. In areas where poor visibility prevented viewing the aquatic vegetation, additional rake samples in between the grid points were taken to sample the vegetation.

Once field work was completed, the data was analyzed on an ArcGIS platform. Data from the survey was used to create an aquatic natural community map and a map of EWM.

3. Results

The results of the inventory are presented below in three sections: a) Grid Point Sampling and Macrophyte Species; b) Rare Species; c) Native Aquatic Vegetation Communities; and d) Eurasian water milfoil.

a. Grid Point Sampling and Macrophyte Species

Collecting data using the grid point sampling method allows for some statistical analysis on the vegetation to be calculated. This includes percent frequency of the different species, species richness and data on EWM throughout the Lake. All 172 grid points as well as all rake samples taken during the qualitative inventory (totaling 209 data points) were used to calculate the statistics on percent frequency and species richness. Sampling points were taken at depths ranging from 1' to 16' deep. The median sampling point depth was 6' deep.

The percent frequency of each species documented during the grid point sampling is shown in Table 2. As can be seen from this data, of the 16 species identified waterweed (*Elodea canadensis*) was the most frequently encountered plant, occurring on 44% of the sampling points. Eelgrass (*Vallisneria americana)* and EWM were also quite abundant, being found at 35% and 26% of the sampling points, respectively. The ubiquitous nature of EWM, the only AIS identified in the study, is discussed in Section 3.d. Aside from these three species, the rest of the species are relatively rare, all being documented at less than 4% of the sampling points. This is consistent with previous findings using the grid point sampling in Lake Carmi (Eichler and Boylen 2010).

Table 2. Percent Frequency of Macrophyte Species

Species	Common Name	Count	Frequency
Eleocharis palustris	marsh spike-rush	2	1%
Elodea canadensis	waterweed	92	44.0%
Heteranthera dubia	water start-grass	7	3.3%
Myriophyllum spicatum	EWM	55	26.3%
Nuphar variegata	common yellow pond-lily	7	3.3%
Potamogeton amplifolius	broad leaved pond-weed	5	2.4%
Vallisneria americana	eelgrass	74	35.4%
Nitella sp.	muskgrass	5	2.4%
Sagittaria graminea	grass-leaved arrowhead	1	0.5%
Schoenoplectus sp.	bulrush	1	0.5%
Potamogeton pusillus	small pondweed	1	0.5%
Najas flexilis	common naiad	3	1.4%
Ceratophyllum demersum	coontail	1	0.5%
Fontanalis sp.	moss	6	2.9%
Nymphaea odorata	waterlily	1	0.5%
Potamogeton perfoliatus	clasping-leaved pondweed	2	1.0%

Grid Point sampling also allows for calculating species richness based on the number of species present at each sampling point, as shown in Table 3. As can be seen from this data, total species richness averages 1.263 species per rake sample. If EWM is excluded from the calculation, native species richness is 0.970 species per sample. The Eichler & Boylen (2010) inventory found that native species richness was 1.5 at depths <18' and 2.28 at depths <6'. The greater species richness documented in 2010 could be the result of a number of factors; natural fluctuations in aquatic plant abundance are known to occur under varying environmental conditions (Rooney and Kalff 2000; Keddy and Reznicek 1986).

Table 3. Species Richness for all Sample Points

Species Richness for All Species	
Sample Size	209
Average	1.263
Standard Error	0.086
Species Richness for Native Species (excludes EWM)	
Sample Size	209
Average	0.970
Standard Error	0.071

The species richness calculations conducted with the grid point sampling, however, can also be misleading. First, certain aquatic macrophyte life forms tend to be under-counted with this method. Plants that form small basal rosettes and some free-floating species are less likely to be captured by the rake than larger, rooted macrophytes. Secondly, because the entire littoral zone is sampled, many of the points were sampled where no aquatic vegetation exists. During the current inventory, 84 of the 209 sample points (40%) occurred where no aquatic plants were present at all. The littoral zone of a lake can be naturally unvegetated for a variety of reasons, mainly related to factors such as depth, substrate and disturbance (Bornette et al. 2011). Therefore, low species richness from the sampling point data may not be a meaningful metric, especially if the areas that are vegetated support a diverse assemblage of species. The location and extent of the unvegetated areas in relation to the vegetated areas may be more significant and easier to track over time. This data is present as natural community polygons Section 3.c.

A list of all species encountered during this inventory was kept while performing the grid point sampling and the Qualitative Method survey. This list is shown in Table 4 along with previous presence/absence data.

Table 4. Presence/Absence Data of Macrophyte Species in Lake Carmi Over Time

Latin Name	Common name	1976	1982	2000	2002	2010	2018
Ceratophyllum demersum	coontail		x	x		x	x
Chara/Nitella	Chara/muskgrass	x	x	x		x	x
Eleocharis acicularis	needle spike-rush	x				x	
Eleocharis palustris	marsh spike-rush						x
Elodea canadensis	water-weed	x	x	x	x	x	x
Eriocaulon aquaticum	pipewort			x	x	x	
Fontinalis sp.	moss					x	x
Heteranthera dubia	water star-grass			x	x	x	x
Juncus sp.	rush	x	x				
Lemna minor	duckweed	x		x	x	x	x
Myriophyllum spicatum	Eurasian water-milfoil	x	x	x	x	x	x
Najas flexilis	common naiad		x	x	x	x	x
Nuphar variegata	common yellow pond-lily	x	x	x	x	x	x
Nymphaea odorata	water lily	x		x	x	x	x
Phragmites australis	common reed				x		
Pontederia cordata	pickerelweed					x	
Potamogeton amplifolius	broad-leaved pondweed	x	x	x	x	x	x
Potamogeton crispus	curly pondweed	x					
Potamogeton epihydrus	ribbon-leaved pondweed			x		x	
Potamogeton foliosus	leafy pondweed		x				
Potamogeton gramineus	grass-leaved pondweed	x		x		x	
Potamogeton natans	floating pondweed					x	
Potamogeton perfoliatus	clasping-leaved pondweed	x	x	x	x	x	x
Potamogeton pusillus	small pondweed			x	x	x	x
Potamogeton richardsonii	Richardson's pondweed	x	x			x	
Potamogeton robbinsii	Robbins' pondweed						x
Potamogeton spirillus	common snailseed pondweed			x		x	
Potamogeton vaseyi	Vasey's pondweed		x			x	
Potamogeton zosteriformis	zigzag pondweed		x	x	x	x	x
Ranunculus aquatilis	white water-crowfoot		x		x	x	
Sagittaria graminea	grass-leaved arrowhead			x	x	x	x
Schoenoplectiella sp.	bulrush					x	
Schoenoplectus acutus	hard-stemmed bulrush						x
Sparganium americanum	common bur-reed						x
Sparganium angustifolium	narrow-leaved bur-reed	x	x		x	x	x
Spirodela polyrrhiza	greater duckweed				x		
Typha sp.	cattail	x	x	x		x	x
Vallisneria americana	eelgrass			x	x	x	x

Data from Vermont Lakes and Ponds Management and Protection Program and (Eichler and Boylen 2010)

As mentioned in the Methodology section, a limited budget prevented conducting qualitative sampling lake-wide. The species presented in Table 4 are therefore mainly species recorded from the grid point sampling and the limited Qualitative Method sampling that was conducted. It is likely that other species (especially those previously recorded) were also present in 2018, albeit at low abundance.

Figure 2. Change in Number of Macrophyte Species Over Time

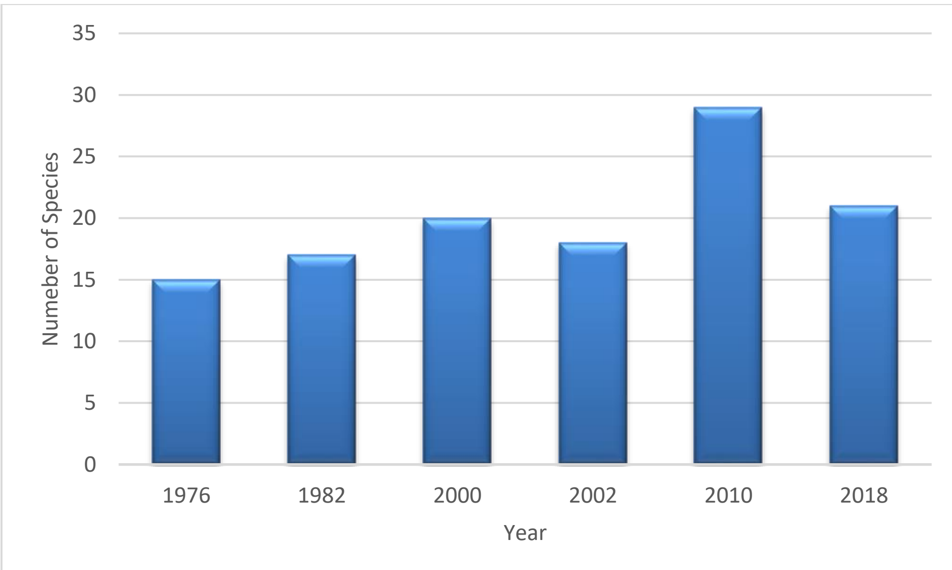

Figure 2 shows the number of species documented in Lake Carmi in the current inventory and the previous 5 inventories. While natural fluctuations in species diversity are common in aquatic systems, it is difficult to determine if the variation seen in Lake Carmi is actual variation or merely a product of differing sampling methodologies. The higher number of species recorded in 2010 may be the result of the more intensive sampling that was conducted. The number of species recorded during the current inventory is otherwise consistent with previous inventories.

The number of species present in a lake is determined by a complex interacting set of factors including trophic status, nutrient availability, water transparency, water temperature, and sediment type (Freedman and Lacoul 2006). As some of these factors change over time, the distribution, abundance and diversity of aquatic macrophytes can also fluctuate. In general, trophic status and water transparency can have significant impacts on species diversity. Mesotrophic-eutrophic lakes have the highest species diversity, while lakes on either trophic extreme (hyper-eutrophic and oligotrophic) have the lowest species diversity (Toivonen and Huttunen 1995; Rørslett 1991). In addition, water transparency and dense phytoplankton growth has been shown to decrease abundance of aquatic macrophytes (Morris et al. 2003; Havens 2003). Algal blooms, like those recently seen in Lake Carmi, may therefore have a negative impact on aquatic macrophyte abundance and diversity, and may explain some of the variation described above.

b. Rare Species

Due to funding constraints, a rare species inventory was not conducted during the current study. However, 2 uncommon or rare species have been documented in Lake Carmi in the past. Each of these occurrences in the lake is summarized below.

Vasey's pondweed (*Potamogeton vaseyii*)

Vasey's pondweed was first documented in Lake Carmi in 1973 on the northern end of the lake. This is an S2-ranked rare species in Vermont. Since 1973, it has been documented in 1982 and in 2010. The 2010 record indicates that it was found in the southern part of the lake. Though this plant is not abundant in Lake Carmi, it appears to be relatively stable at low abundance. This plant was not documented during the grid point sampling of the current inventory. However, since this method can omit species that are present at low abundance, this should not be interpreted as confirmation of its absence in 2018.

White water-crowfoot *(Ranunculus aquatilis)*

White water-crowfoot is a free-floating aquatic plant in the buttercup family which is considered uncommon (S3-ranked) in Vermont. This species has been documented in Lake Carmi in 1982, 2002 and 2010. Like Vasey's pondweed, it appears to be stable at low abundance in the lake. This species was not documented in the current inventory.

Bulrush (*Schoenoplectiella sp.)*

This genus of bulrush was recorded during the 2010 aquatic plant inventory of Lake Carmi. This genus was recently split from the larger *Schoenoplectus* genus, which contains many common species of bulrush. There are two species of *Schoenoplectiella*, Pursh's bulrush (*Schoenoplectiella purshianus*) and Smith's bulrush (*Schoenoplectiella smithii*). Pursh's bulrush is considered uncommon (S3-ranked) in Vermont and Smith's bulrush is very rare- rare (S1S2-ranked) in the state. The 2010 report (Eichler and Boylen 2010) noted that *Schoenoplectiella sp.* was documented multiple times in Lake Carmi, dating back to 1982. While species from the larger *Schoenoplectus* genus have been consistently documented in the lake (including in the current inventory), no record of either species in the *Schoenoplectiella* genus have been recorded prior to 2010. Given this information, it is likely that the 2010 inventory mistakenly listed *Schoenoplectiella* in place of *Schoenoplectus* and neither of the rare species were documented.

c. Native Aquatic Vegetation Communities

A natural community is an interacting assemblage of organisms, their physical environment, and the natural processes that affect them (Thompson and Sorenson 2005). Most studies done by scientists on natural communities has been done in terrestrial systems. Much work still needs to be done on classifying groups of aquatic plants into natural communities. The native aquatic vegetation documented in Lake Carmi has been categorized into three different types: the Eelgrass-Water Stargrass Community, the Water Lily Aquatic Community, and the Deep Bulrush Marsh Community. These three communities appear to be widespread and abundant types in the region that have been documented in other nearby water bodies (Arrowwood Environmental and Lake Champlain Committee 2013; Arrowwood Environmental 2018). A map of these communities is shown in Figure 3 and each type is described below.

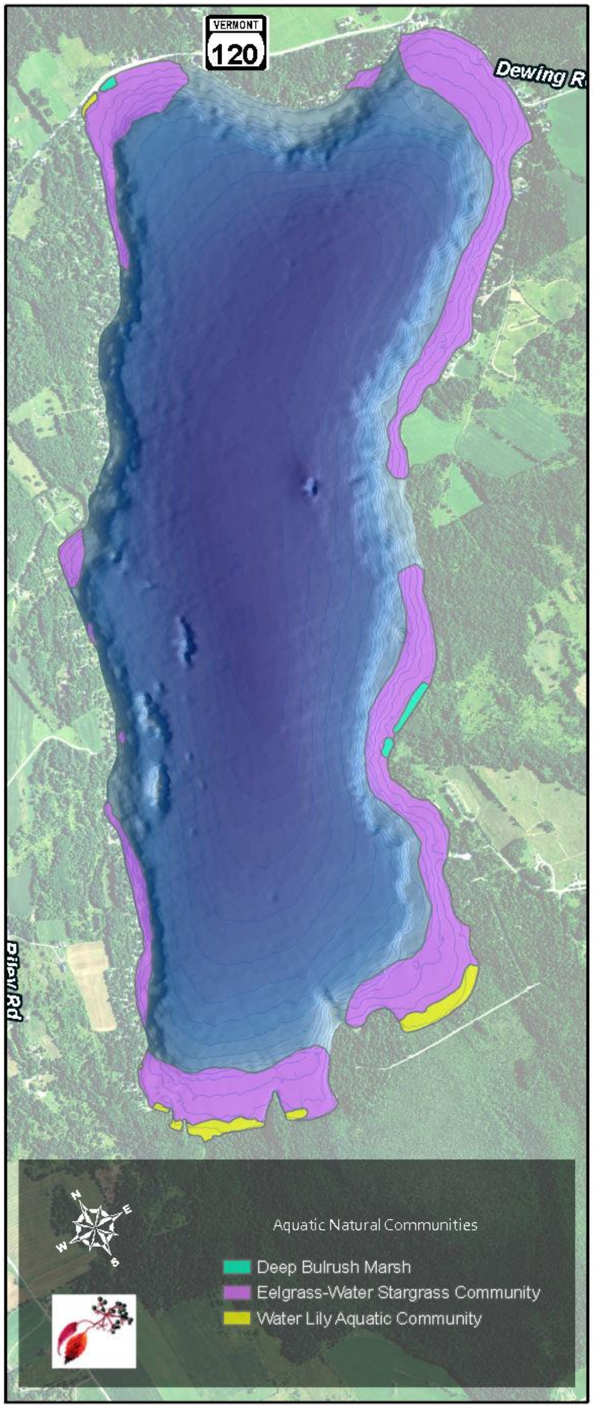

Figure 3. Native Aquatic Communities in Lake Carmi

As can be seen in Figure 3, not all the littoral zone in the lake is occupied by aquatic vegetation. The largest occurrences of aquatic vegetation occur in the bays on the northern and southern ends of the lake. The substrate in these areas ranges from sand and silty sand to muck. The densest areas of native vegetation occur in areas with finer substrates. Many areas mapped as Eelgrass- Water Stargrass Community, especially along the eastern and western shores, have more coarse substrates such as rocks and cobble mixed with sands. These areas often exhibit a patchy distribution of aquatic vegetation.

Eelgrass-Water Stargrass Community

The Eelgrass-Water Stargrass Community is the most common aquatic type in Lake Carmi. This is the community that also occupies large areas nearby in Lake Champlain. In Lake Carmi, eelgrass (*Vallinseria americana*), waterweed (*Elodea canadensis*) and clasping-leaved pondweed (*Potamogeton perfoilatus*) are the most common components. Other common species include large-leaved pondweed (*P. amplifolius*) and water stargrass (*Heteranthera dubia*). As can be seen from the frequency data in Table 2 above, common waterweed is abundant in Lake Carmi. This species can form small, dense, nearly monotypic stands, especially in areas of sedimentation and increased nutrient input like the mouths of the inlets. Eelgrass is also widespread and is a key component of this aquatic community in the lake.

This community includes the shallow sandy areas up to the shoreline as well as deeper areas 10-12' deep with silty sands. Vegetation is most abundant and diverse in the 3-8' depth range. The substrate includes sandy, silty sand and cobble/rock mixed with sand. As mentioned above, the areas with finer sediment tend to harbor more diverse and abundant vegetation, whereas the coarse sediment types exhibit patchy vegetation.

The occurrence of this community type on the northern shore, including the public beach area, is in fairly good condition and includes the shallow, sandy area of the beach which contains very little EWM. The occurrences along the eastern and western shores of the lake are relatively narrow bands of vegetation out to 8 feet in depth. Vegetation in these areas is somewhat patchy, with some localized areas containing no vegetation at all. The largest occurrences of this type are in the two southern bays of the lake. In contrast to the examples along the eastern and western shores, both these sites are densely vegetated and are diverse, intact examples of this community. There are infestations of EWM within both of these sites, but there are also areas where EWM is sparse and native species dominate. These southern areas harbor the largest and most intact examples of native aquatic vegetation in the lake.

Water Lily Aquatic Community

The Water Lily Aquatic Community is a common and widespread community throughout the region. It occupies shallow, sheltered bays of many water bodies and is dominated by floating-leaved aquatic plants. Aside from a small occurrence on the northern end of the lake by the boat launch, most of this community occurs in the shallow, southern end of the lake.

The vegetation in this community consist of both a floating-leaved strata and an submerged strata. The floating leaved strata is dominated by yellow pond lily (*Nuphar variegata*) with smaller amount of white water lily (*Nymphaea odorata*) and the floating narrow-leaved bur-reed

(*Sparganium angustifolium*). These floating-leaved species typically cover 70-90% of the lake surface. The submerged layer is similar in composition to the adjacent Eelgrass-Water Stargrass community. Eelgrass, Eurasian water milfoil, perfoliate-leaved pondweed, and the aquatic moss *Fontanalis sp.* are common. Percent cover is variable, ranging from 50-90% and is inversely proportional to the percent cover of the floating-leaved strata.

The development of this community requires protected bays which typically result in the development of organic (mucky) substrates. It can occur from the shoreline out to depths of 3 feet where the floating-leaved species become sparser and it grades into the Eelgrass-Water Stargrass community.

The relatively large areas occupied by the Water Lily Aquatic Community in the southern end of the lake are intact, relatively undisturbed examples of this type. Though EWM is present at low cover, it does not appear to be having a significant detrimental impact on these communities.

Deep Bulrush Marsh

The Deep Bulrush Marsh is a wetland community that colonizes the sandy substrates of permanently flooded lake margins. It is common in nearby Lake Champlain and has been mapped at three locations in Lake Carmi: one on the northern shore near the boat launch and two on the eastern shore at the inlet of Marsh Brook.

This community is characterized by presence of the emergent bulrush (*Schoenoplectus spp*.) and water spikerush (*Eleocharis palustris*). Both these species are present in Lake Carmi, though water spikerush is more common. Percent cover of these species ranges from 25-60%. The floating-leaved white water lily is also mixed in with the bulrush and spikerush. Submerged aquatic vegetation is often present below the bulrush and spikerush plants and is typically dominated by eelgrass and waterweed.

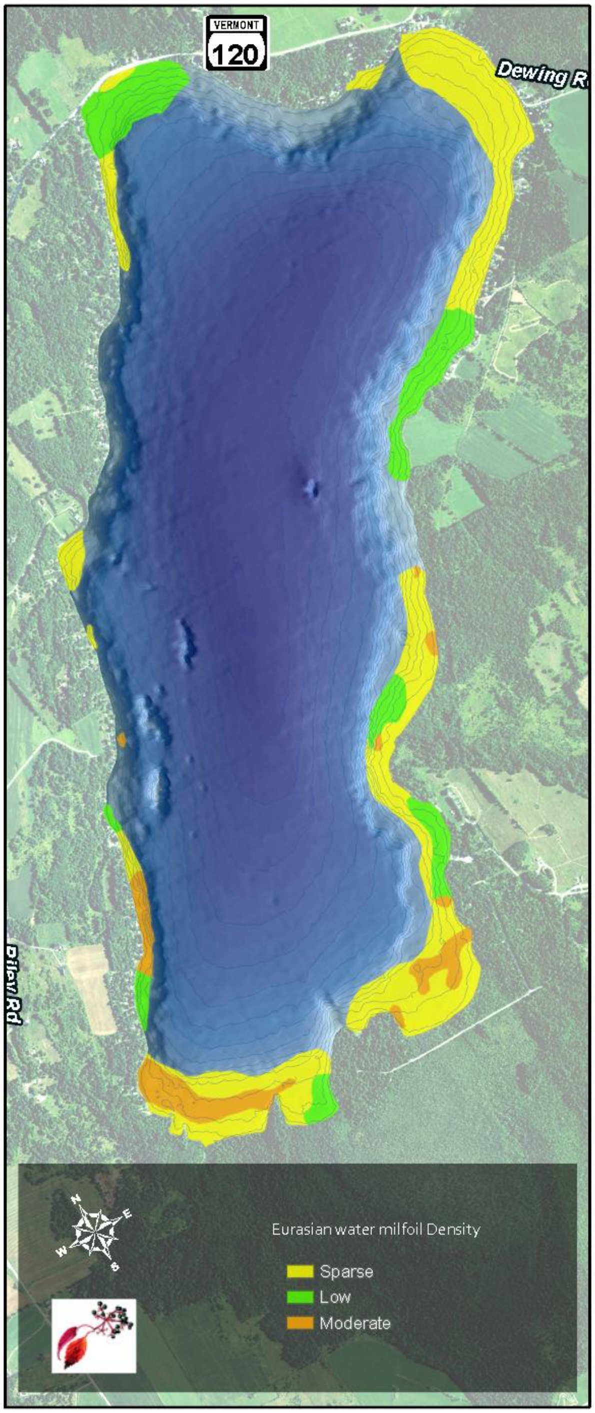

Figure 4. Distribution and Abundance of Eurasian water milfoil in Lake Carmi

This community occupies shallow, sandy areas. Unlike the Water Lily Community, it can occur in sandy sediments and occupy areas that are exposed to considerable wave action. All occurrences in Lake Carmi are located in water depths less than 2 feet.

d. Eurasian Water Milfoil

Eurasian water milfoil has been present in Lake Carmi for more than 30 years. Starting in 1985, frequent mechanical harvesting of this invasive species has occurred including yearly mechanical harvesting since 2011. The harvesting activities primarily occur in the northern and southern ends of the lake, where EWM is most prevalent. According to Vermont DEC, 43.25 cubic yards of EWM were removed from Lake Carmi in 2018. Most of this 2018 mechanical harvesting occurred in the northeastern end of the lake. This report also noted that EWM abundance in the lake in 2018 was less than previous years due to lack of rainfall and less phosphorus loading.

The current distribution and abundance of EWM in the lake is shown in Figure 4 and includes areas of Sparse, Low and Moderate cover. A summary of each of these categories is presented in Table 5. As noted in the natural community section above (Section 3.c), there are areas in the lake that are mapped as unvegetated. It should be noted that EWM is found throughout the lake, and even areas mapped as "unvegetated" may contain small amounts of EWM.

Table 5. Summary of EWM Infestations in Lake Carmi

EWM Density	% Cover Class	# of Occurrences	Total Acreage
Sparse	<5%	10	146
Low	5-25%	7	60
Moderate	25-50%	9	33
Dense	50-100%	0	0

As can be seen in Table 5, most of the occurrences and acreage of EWM in the lake consist of Low to Sparse cover. During the current inventory, while EWM was widespread and abundant, no monotypic "Dense" stands of this species were documented. This is likely the result of recent and ongoing management of EWM in the lake. Field work for this current study was conducted in mid-late August, after most of the 2018 mechanical harvesting of EWM occurred. It is likely that Dense stands of EWM would have been recorded prior to mechanical harvesting. As noted above, most of the EWM harvesting occurred in the northeastern end of the lake, where only "Sparse" cover was mapped.

Moderate cover was documented in the southern bays of the lake where minimal mechanical harvesting occurred. Given that the southern bays host the largest, most intact examples of natural aquatic vegetation, these areas should not be ignored during the EWM harvesting process. While this yearly harvesting may not eradicate the EWM, it may allow for more competition from native species by decreasing the abundance of EWM, at least for part of the growing season.

4. Conclusion

As part of the effort to mitigate the impacts of phosphorus loading into Lake Carmi, the Vermont DEC has funded a study of the aquatic macrophytes to act as a baseline data for potential lake management. This study used the grid-point method and qualitative method sampling to map the distribution and abundance of aquatic macrophytes in the lake. A total of 22 different aquatic species were documented in the lake, with the most common species being waterweed, eelgrass and Eurasian water milfoil. This study also mapped and assessed three different aquatic natural communities in the lake: the Eelgrass-Water Stargrass Community, the Water Lily Aquatic Community and the Deep Bulrush Marsh. The Eelgrass-Water Stargrass community is the most abundant native plant community in the lake, and habitat for most of the plant diversity. Finally, the distribution and abundance of EWM was mapped in Lake Carmi after 2018 mechanical harvesting was conducted. This invasive species was found throughout the lake, with moderate density areas remaining in the southern bays of the lake, where harvesting effort was minimal.

References Cited

Arrowwood Environmental. 2018. "Fairfield Pond Aquatic Plant Inventory." *Report Submitted to the Fairfield Pond Recreation Association and Town of Fairfield, VT*, 1–27.

Arrowwood Environmental and Lake Champlain Committee. 2013. "Lake Champlain Northeast Arm Aquatic Invasive Species Early Detection and Control Project." *Report Submitted to the Lake Champlain Basin Program*.

Bornette, Gudrun, Sara Puijalon, Claude Bernard, and University Lyon. 2011. "Response of Aquatic Plants to Abiotic Factors: A Review." https://doi.org/10.1007/s00027-010-0162-7.

Eichler, Lawrence, and Charles Boylen. 2010. "Lake Carmi Aquatic Plant Survey." *Darrin Fresh Water Institute Report*, no. October.

Freedman, Bill, and Paresh Lacoul. 2006. "Environmental Influences on Aquatic Plants in Freshwater Ecosystems." https://doi.org/10.1139/A06-001.

Hauxwell, Jennifer, Susan Knight, Kelly Wagner, Alison Mikulyuk, Michelle Nault, Meghan Porzky, Shaunna Chase, and J Hauxwell. 2010. "Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry and Analysis, and Applications." https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/ecology/Aquatic Plants/PI-Protocol-2010.pdf.

Havens, Karl E. 2003. "Submerged Aquatic Vegetation Correlations with Depth and Light Attenuating Materials in a Shallow Subtropical Lake." *Hydrobiologia*. Vol. 493. http://cescos.fau.edu/gawliklab/papers/HavensKE2003.pdf.

Keddy, P.A., and A.A. Reznicek. 1986. "Great Lakes Vegetation Dynamics: The Role of Water Levels and Buried Seeds." *J. Great Lakes Res.* 12 (1):25–36. http://drpaulkeddy.com/pdffiles/KeddyReznicek1986.pdf.

Morris, Kay, Paul C. Bailey, Paul I. Boon, and Leesa Hughes. 2003. "Alternative Stable States in the Aquatic Vegetation of Shallow Urban Lakes. Catastrophic Loss of Aquatic Plants in Consequent to Nutrient Enrichment." *Marine and Freshwater Research* 54 (3). CSIRO PUBLISHING:201. https://doi.org/10.1071/MF02003.

Rooney, Neil, and Jacob Kalff. 2000. "Inter-Annual Variation in Submerged Macrophyte Community Biomass and Distribution: The Influence of Temperature and Lake Morphometry." *Aquatic Botany* 68 (4). Elsevier:321–35. https://doi.org/10.1016/S0304-3770(00)00126-1.

Rørslett, Bjørn. 1991. "Principal Determinants of Aquatic Macrophyte Richness in Northern European Lakes." *Aquatic Botany* 39 (1–2). Elsevier:173–93. https://doi.org/10.1016/0304-

3770(91)90031-Y.

Thompson, E.H., and E.R. Sorenson. 2005. *Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont*. The Nature Conservancy and the Vermont Department of Fish and Wildlife.

Toivonen, Heikki, and Pertti Huttunen. 1995. “Aquatic Macrophytes and Ecological Gradients in 57 Small Lakes in Southern Finland.” *Aquatic Botany* 51 (3–4). Elsevier:197–221. https://doi.org/10.1016/0304-3770(95)00458-C.

Vermont Agency of Natural Resources. 2018. “Lake Carmi Crisis Response Plan.”

Vermont Agency of Natural Resources Department of Environmental Conservation. 2006. “Water Quality Division - Field Methods Manual,” 1–117.