Paradise Lake Aquatic Plant Survey 2008

by

Tip of the Mitt Watershed Council

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SUMMARY

Aquatic plants provide many benefits to aquatic ecosystems, but can become a recreational nuisance when growth is excessive. The introduction of non-native aquatic plant species often exacerbates the problem. To assist aquatic plant and lake management efforts, the Paradise Lake Association contracted with Tip of the Mitt Watershed Council to conduct an aquatic plant survey on Paradise Lake in northern Emmet and Cheboygan Counties, Michigan. It was conducted during the fall of 2008.

Shallow areas, invasive species, and nutrient pollution are key factors believed to contribute to heavy aquatic plant growth in Paradise Lake. Aquatic plants have been found inhabiting depths in excess of 20 feet in other lakes in the region. Due to the fact that Paradise Lake is a shallow lake with a maximum depth of ~17 feet, aquatic plants could potentially colonize all areas of the lake.

Eurasian watermilfoil (*Myriophyllum spicatum*) has been in Paradise Lake for a minimum of 13 years, is non-native and able to outcompete native aquatic plants. Zebra mussels (*Dreissena polymorpha*) have only recently been reported as being abundant. Zebra mussels disrupt the ecosystem and potentially exacerbate nuisance aquatic plant growth.

Evidence of nutrient pollution was found along the Paradise Lake shoreline during a shoreline survey conducted in 2002. Signs of nutrient pollution were found primarily in two concentrated areas: throughout most of Carlton Cove and along the north shore of the lake between Elm and Pine Streets. Excess nutrients originating from shoreline properties likely contribute to the dense plant growth in these areas.

For this 2008 survey, specimens were collected and plant densities documented at 198 sites throughout Paradise Lake. Additional information was noted at sample sites to assist in delineating plant communities. Visible plant community lines were also mapped using a GPS (global positioning system). Sampling effort was biased toward areas of dense vegetation, particularly in areas with heavy Eurasian watermilfoil growth.

A total of 24 aquatic plant taxa were documented during the survey. Eurasian watermilfoil and slender naiad (*Najas flexilis*) were the most commonly collected species and dominant at the greatest number of sample sites. Heavy- or very heavy-density plant growth was found at 28% of sites sampled. When expressed in terms of the lake's surface area, about 21% contained heavy or very heavy-density plant growth.

Delineation of plant communities showed that a substantial portion of Paradise Lake, ~42%, contains little or no aquatic vegetation. Muskgrass (Ch*ara spp.*) and pondweed (*Potamogetonaceae*) communities were the most extensive in Paradise Lake, each covering over 180 acres. Large, heavy-density Eurasian watermilfoil beds were found in the western basin and along the northern shore of the lake. Heavy-density pondweed beds were found in the same general areas, but were not as extensive as Eurasian watermilfoil beds.

In general, there are four major approaches to aquatic plant management as well as combinations of these. Options include: do nothing and let nature take its course; otherwise, attempt to control problematic aquatic plant growth using chemical, physical or biological treatment. Aquatic plant control options should be carefully evaluated, weighing the positive against the negative aspects of each one. Drastic alteration of the aquatic plant community could have far-reaching and devastating impacts on fisheries and the entire ecosystem.

The Paradise Lake Association should share results from this survey to maximize benefits and assist in lake management efforts. Survey results should be used to develop an aquatic plant management plan. Nutrient pollution problem areas have been identified and should be addressed.

Biological control using weevils (*Euhrychiopsis lecontei)* native to the region should continue to be used to control nuisance Eurasian watermilfoil growth because it has been effective in the past and is an environmentally safe and potentially long-term solution. Heavy-density pondweed growth is not as extensive and problematic as Eurasian watermilfoil growth and does not need to be addressed unless it expands. Efforts should be taken to preserve the biological diversity of Paradise Lake.

Information and education efforts should be undertaken to promote an understanding of aquatic plant communities and the lake ecosystem among riparian property owners and other lake users, as well as encourage behaviors and practices that protect and improve lake water quality. Optimally, aquatic plant surveys should be conducted on the lake every 5-10 years to guide aquatic plant management decisions and track changes over time.

INTRODUCTION

Background:

Aquatic plant communities provide numerous benefits to lake ecosystems. Aquatic plants provide habitat, refuge, and act as a food source for a large variety of waterfowl, fish, aquatic insects, and other aquatic organisms. Like their terrestrial counterparts, aquatic plants produce oxygen as a by-product of photosynthesis. Aquatic plants utilize nutrients in the water that would otherwise be used by algae and potentially result in nuisance algae blooms. A number of aquatic plants, including bulrush, water lily, cattails, and pickerel weed help prevent shoreline erosion by absorbing wave energy and moderating currents. Soft sediments along the lake bottom are held in place by rooted aquatic plants.

Lake systems with unhealthy or reduced aquatic plant communities will likely experience declining fisheries due to habitat and food source losses. Aquatic plant loss may also cause a drop in daytime dissolved oxygen levels and increased shoreline erosion. If native aquatic plants are removed through harvesting or herbicide application, resistance of the naturally occurring plant community is weakened and can open the door for invasive species, such as curly-leaf pondweed or Eurasian watermilfoil.

In spite of all the benefits associated with aquatic plants, some aquatic ecosystems suffer from overabundance, particularly where non-native nuisance species have been introduced. Excessive plant growth can create a recreational nuisance by making it difficult or undesirable to boat, fish and swim, but it also has the potential to cause aquatic ecosystem disruptions. In lakes plagued by nuisance plant species, it sometimes becomes necessary to develop and implement programs to control excessive growth and non-native species.

Aquatic plant management is a critical component of lake management. Thus, an important first step in developing a sound lake management program is to survey the aquatic plant communities to document species, abundance, density, and the presence or absence of non-native species. In 2008, the Paradise Lake Association contracted with Tip of the Mitt Watershed Council to perform a comprehensive aquatic plant survey of Paradise Lake. Additional funding for the survey was provided by the Carp Lake

Township board. The results of this survey will provide the lake association with an informational tool to assist in lake management. Watershed Council staff collected field data during the fall of 2008. Survey field methods, data management procedures, project results, and discussion of results are contained in this report.

History:

Although the exact year of introduction of Eurasian watermilfoil is uncertain, its presence in Paradise Lake was confirmed during an aquatic plant survey conducted by Tip of the Mitt Watershed Council in 1996. The 1996 aquatic plant survey documented ten commonly occurring species of aquatic plants: *Chara spp., Najas flexilis, Potamogeton amplifolius, Potamogeton praelongus, Vallisneria americana, Myriophyllum heterophyllum, Myriophyllum spicatum, Elodea canadensis, and Utricularia spp.* Four distinct vegetation communities were mapped out during the 1996 survey, including: 1) Unvegetated shallow lake areas (29.5% of the lake), 2) Sparsely vegetated areas (27.9% of the lake), 3) Diverse, patchy assemblage of plants, generally occurring in low to moderate densities (26.0% of the lake), and 4) very dense plant growth reaching the surface dominated by Eurasian watermilfoil and whitestem pondweed (16.6% of the lake).

Following the 1996 aquatic plant survey, the Paradise Lake Association began looking into aquatic plant control options, eventually settling upon an innovative biological control approach using an aquatic weevil native to Michigan's lakes. In 1998, Paradise Lake became the first lake in Michigan where weevils were stocked to control problematic Eurasian watermilfoil growth. The Paradise Lake Association contracted with EnviroScience, Inc. to stock weevils and perform surveys to assess control efforts.

Weevils were stocked in Paradise Lake by EnviroScience, Inc. for three consecutive years from 1998 to 2000 and assessment surveys were performed through 2001. Approximately 10,300 weevils were stocked in Paradise Lake in three locations in 1998, 3000 additional weevils stocked in 1999, and a final stocking of 1000 weevils occurred in 2000 (EnviroScience, 2001). Final assessment surveys in 2001 showed weevils and damage indicative of weevils in two of the four monitoring sites. Survey results from the other two monitoring sites were very encouraging: the dense Eurasian watermilfoil at these sites had virtually disappeared.

From 2002 to 2007, aquatic plant surveys were not performed, but aquatic plant growth trends were observed and reported by both the Paradise Lake Association and Tip of the Mitt Watershed Council. Based on communications with the Paradise Lake Association during this time period, biological control efforts using the weevil effectively reduced the quantity of nuisance Eurasian watermilfoil growth. Eurasian watermilfoil growth in the lake declined for several years after stocking weevils, reaching maximum effectiveness in 2004 when very little watermilfoil growth was observed. Observations by Tip of the Mitt Watershed Council staff engaged in monitoring and other activities on Paradise Lake in this time period concur with those of the Paradise Lake Association: that Eurasian watermilfoil growth was noticeably diminished. Furthermore, during an underwater ROV (remotely operated vehicle) field trip in Paradise Lake in 2005, SEE-North staff familiar with Eurasian watermilfoil beds in the lake reported "being amazed by a lack of Eurasian watermilfoil in the center of the northwest basin of the lake, where it had been abundant previously".

Although aquatic plant surveys were not performed during the 2002 to 2007 time period, a shoreline survey was conducted in 2002 by Tip of the Mitt Watershed Council. Shoreline surveys are performed to assess shoreline conditions that have the potential to negatively impact the lake's water quality, usually with a focus on nutrient pollution. This 2002 shoreline survey found evidence of nutrient pollution (indicated by noticeable growth of *Cladophora* or other filamentous algae) at 73 locations on Paradise Lake, or about 19% of properties. The locations of nutrient pollution indicators were concentrated in Carlton Cove from Gill Road to Ashbaugh Point and along the north shore of the lake from Elm to Pine Streets. It is important to note areas with signs of nutrient pollution because nutrient pollution stimulates plant growth and can lead to nuisance aquatic plant growth.

In 2006, a resurgence in dense aquatic plant growth began to occur in Paradise Lake. Aquatic plant specimens were collected from areas of resurgent dense growth by the Paradise Lake Association and delivered to the Tip of the Mitt Watershed Council for identification. Specimens delivered to the Watershed Council office were determined to be native plant species, primarily consisting of pondweeds. In 2007, resurgent plant growth continued and Eurasian watermilfoil beds reappeared in some of the same historical locations.

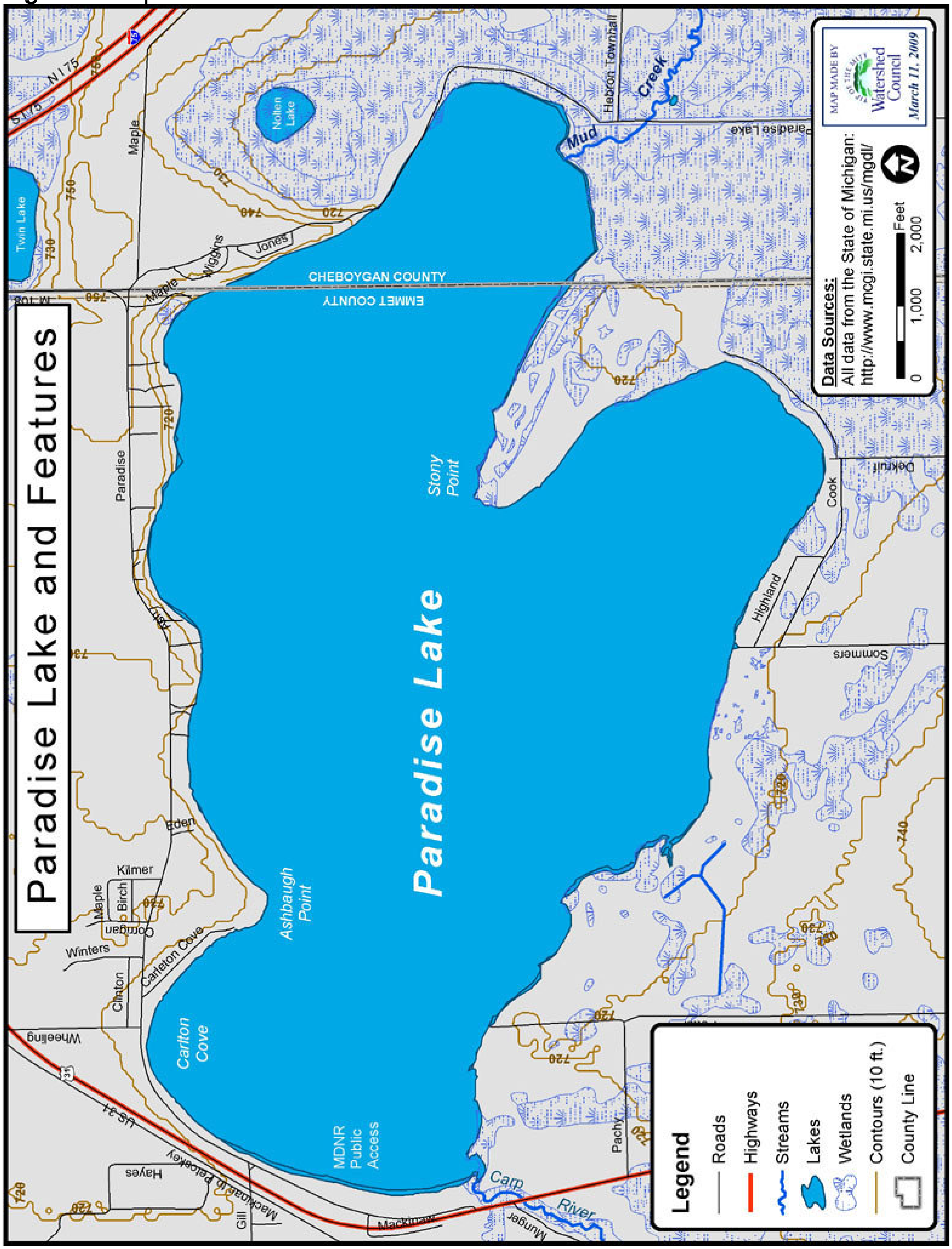
The resurgence of dense aquatic plant growth generated much concern among shoreline residents of Paradise Lake, as well as other lake users. The rising concern prompted the Paradise Lake Association to hold a public meeting in July of 2008 to discuss the issue and get input from a variety of water resource/management professionals. Representatives from Michigan Department of Environmental Quality (MDEQ), Michigan Department of Natural Resources (MDNR), Tip of the Mitt Watershed Council, EnviroScience, Inc. and Angers Lake Front Services, Inc. were available to provide input and respond to questions and concerns. Following this meeting, the Paradise Lake Association arranged to have an aquatic plant survey conducted by the Watershed Council to assess the current status of aquatic plants in Paradise Lake and thereby, assist the association in making informed aquatic plant management decisions.

Study area:

Paradise Lake is located in the northern tip of the Lower Peninsula of Michigan; in Carp Lake Township of Emmet County and Hebron Township of Cheboygan County. Based upon digitization of aerial orthophotographs acquired from the Emmet and Cheboygan County GIS (Geographical Information System) Departments (2004), the shoreline of Paradise Lake proper measures 9.7 miles and lake surface area totals 1,947 acres. Paradise Lake is approximately 3 miles long, gradually widening from the east to west with two distinct lobes on the western end split by Stony Point (Figure 1). Another prominent point, Ashbaugh Point, is located on the west end of the northern shoreline and the lake area to the west of this point is referred to as Carlton Cove. An MDNR boat launch is situated near the center of the west shore of the lake.

Paradise Lake is relatively shallow, the majority of the lake area being less than 10 feet deep. Bathymetry maps from the State of Michigan as well as the Sportsman's Connection Fishing Map Guide show the deepest area located in the north central part of the lake with a maximum depth of 15 to 17 feet deep. Accordingly, a maximum depth of 16.7 feet has been documented by Tip of the Mitt Watershed Council staff during water quality monitoring activities. The deepest spot is located in a narrow, long trough exceeding 10 feet in depth that extends across most of the lake from east to west in the northern half of the lake. A shallow plateau of five feet of depth and less is found in the

Figure 1. Map of Paradise Lake: Features



center of the lake.

Paradise Lake is a drainage lake with water flowing into and out of the lake. The primary inlet is Mud Creek on the eastern end of the lake and the only outlet is the Carp River in the southwest end. A large wetland complex envelopes the eastern end of the lake and additional wetlands are found along the southern shoreline.

Paradise Lake is part of the larger Carp River watershed, which according to GIS files acquired from the Michigan Geographic Data Library, encompasses approximately 29,573 acres of land and water. The watershed stretches approximately 15 miles from a southeast to northwest direction; the Carp River emptying into Lake Michigan at Cecil Bay (Figure 2).

Land cover statistics for the Carp River watershed were generated using remotely sensed data from the year 2000, which was produced as part of the Coastal Great Lakes Land Cover project (Table 1). Based on these data, there is little agricultural landcover within the watershed (~8%) and even less urban (~3.3%). The majority of the watershed's landcover is natural; consisting of wetlands, forest, and grassland.

Table 1. Paradise Lake watershed 2000 land cover statistics.

Land Cover Type	Acreage	Percentage
Agriculture	2446.29	8.27
Barren	39.15	0.13
Forested	6329.48	21.39
Grassland	3153.35	10.66
Scrub/shrub	627.01	2.12
Urban	975.35	3.30
Water	2057.48	6.95
Wetlands	13960.19	47.18
TOTAL	29588.29	100.00

The water quality of Paradise Lake has been monitored consistently for many years. The Paradise Lake Association has actively supported water quality monitoring programs on Paradise Lake, providing volunteers for the volunteer water quality monitoring programs coordinated by the Watershed Council. In addition, Paradise Lake is monitored as part of the Comprehensive Water Quality Monitoring program (CWQM). Based on data collected as part of the Watershed Council's Volunteer Lake Monitoring Program, Paradise Lake generally falls into the mesotrophic category (Figure 3).

Figure 2. Map of the Carp River Watershed.

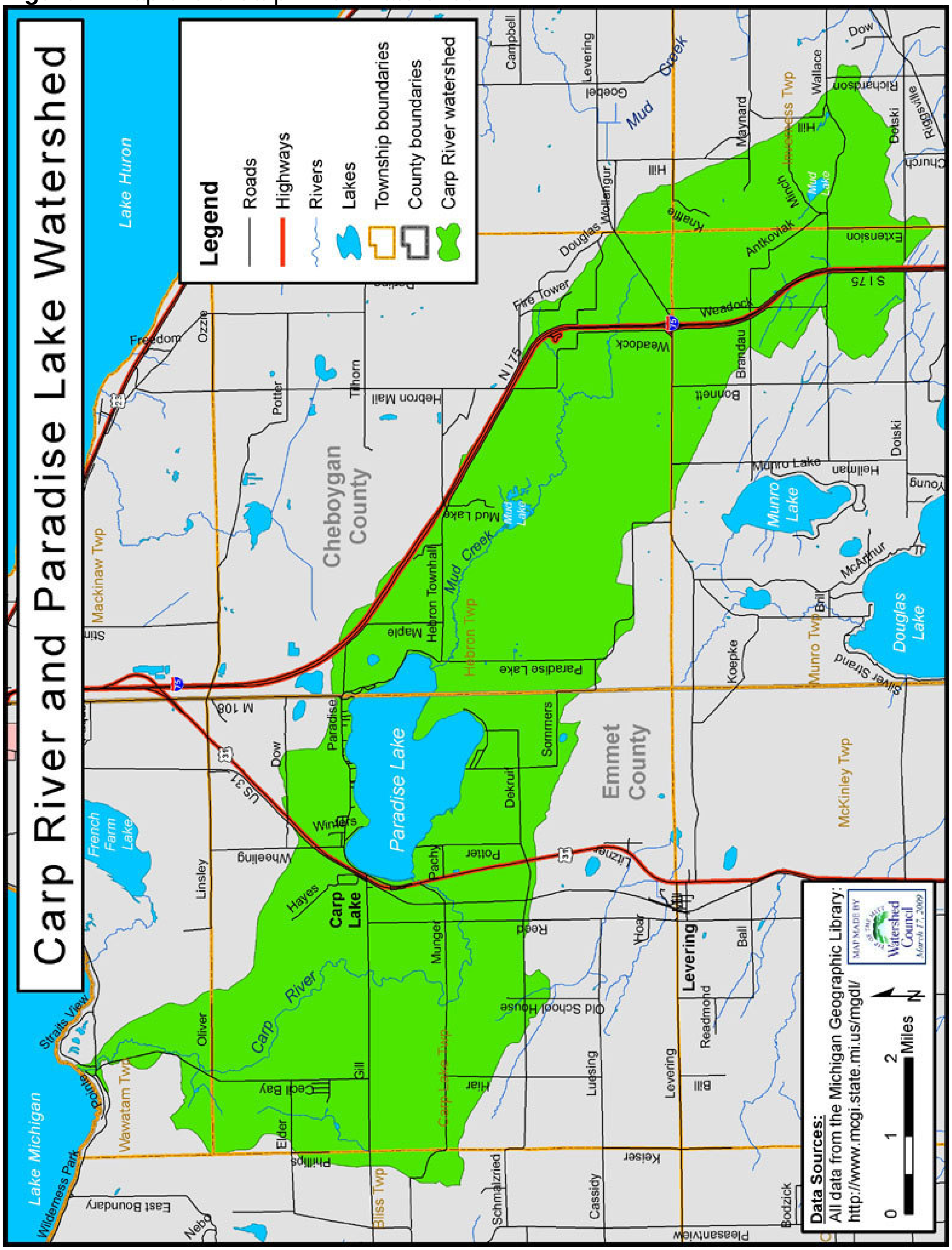
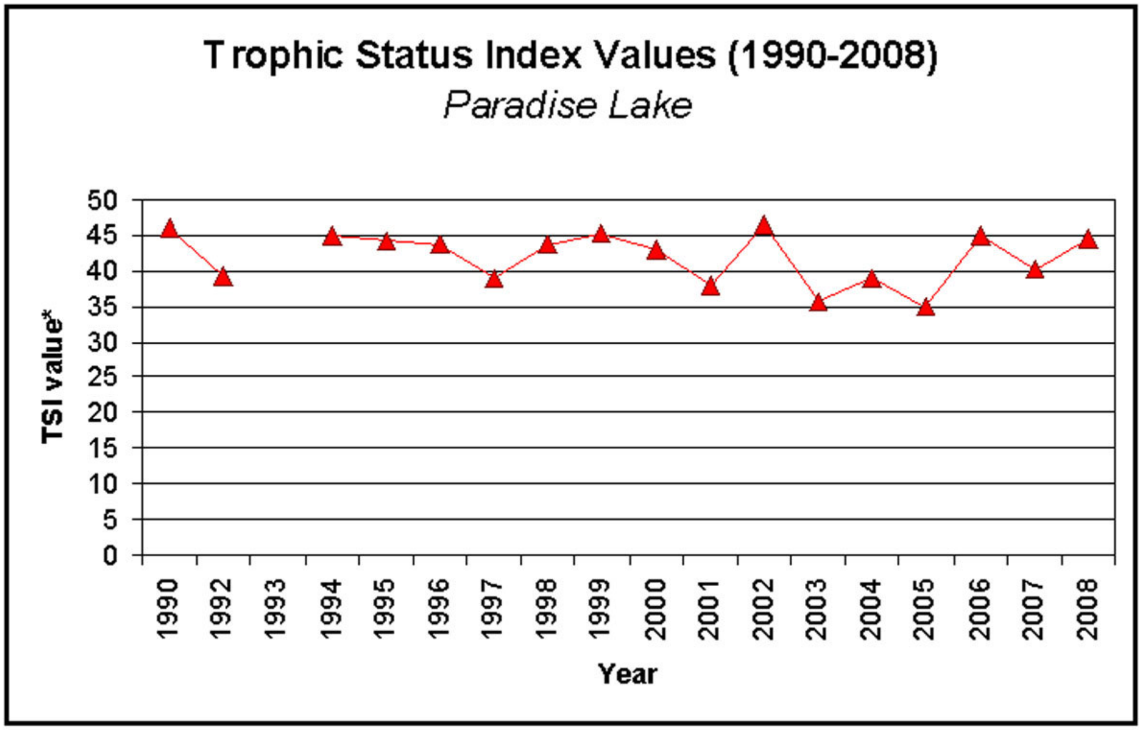


Figure 3. Chart of trophic status index data from Paradise Lake

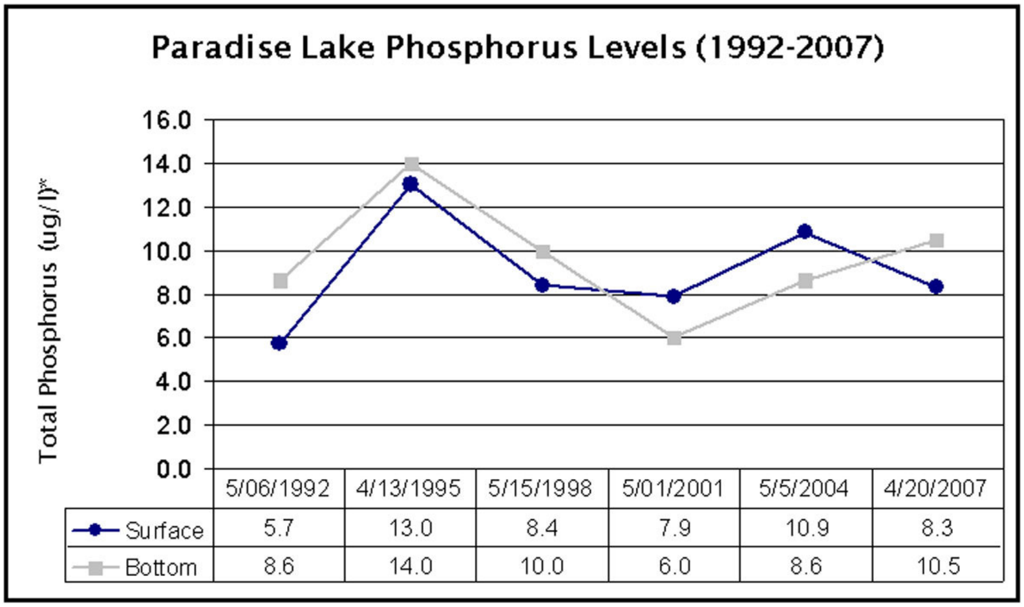


**TSI determines trophic status of lake: 0-38 = oligotrophic (low productive system), 39-49 = mesotrophic (moderately productive system), and 50+ = eutrophic (highly productive system).*

Mesotrophic lakes are in the middle of the road in terms of biological productivity; somewhere between the nutrient poor large, deep lakes with lackluster fisheries and the overly productive small, shallow lakes with excessive algae and plant growth. Total phosphorus data collected in the CWQM program show that levels have gone up and down during the last 20 years, averaging around 10 parts per billion (PPB), which is typical for high quality lakes of northern Michigan (Figure 4).

Surveys by MDNR show that Paradise Lake supports a mixed warm-water fishery. Fish species collected during a 2004 survey include black crappie, bluegill, brown bullhead, largemouth bass, northern pike, pumpkinseed sunfish, rock bass, smallmouth bass, walleye, and white sucker. Additional forage fish collected during the survey include bluntnose minnow, logperch, mimic shiner, northern redbelly dace, sand shiner, and spottail shiner. Over 300,000 walleye were stocked in Paradise Lake from 1996 to 2006.

Figure 4. Chart of phosphorus data from Paradise Lake



**Total phosphorus measured in ug/l, which is milligrams per liter or parts per billion.*

METHODS

Field data for the Paradise Lake aquatic plant survey were collected in the fall of 2008, beginning on September 15 and finishing on October 6. Aquatic plants were documented in all lake areas. The aquatic plant communities of Paradise Lake were surveyed by documenting aquatic plant types and densities at sample sites and delineating evident aquatic plant communities. After performing the survey, data collected in the field were processed and used to produce a map of the lake's aquatic plant communities.

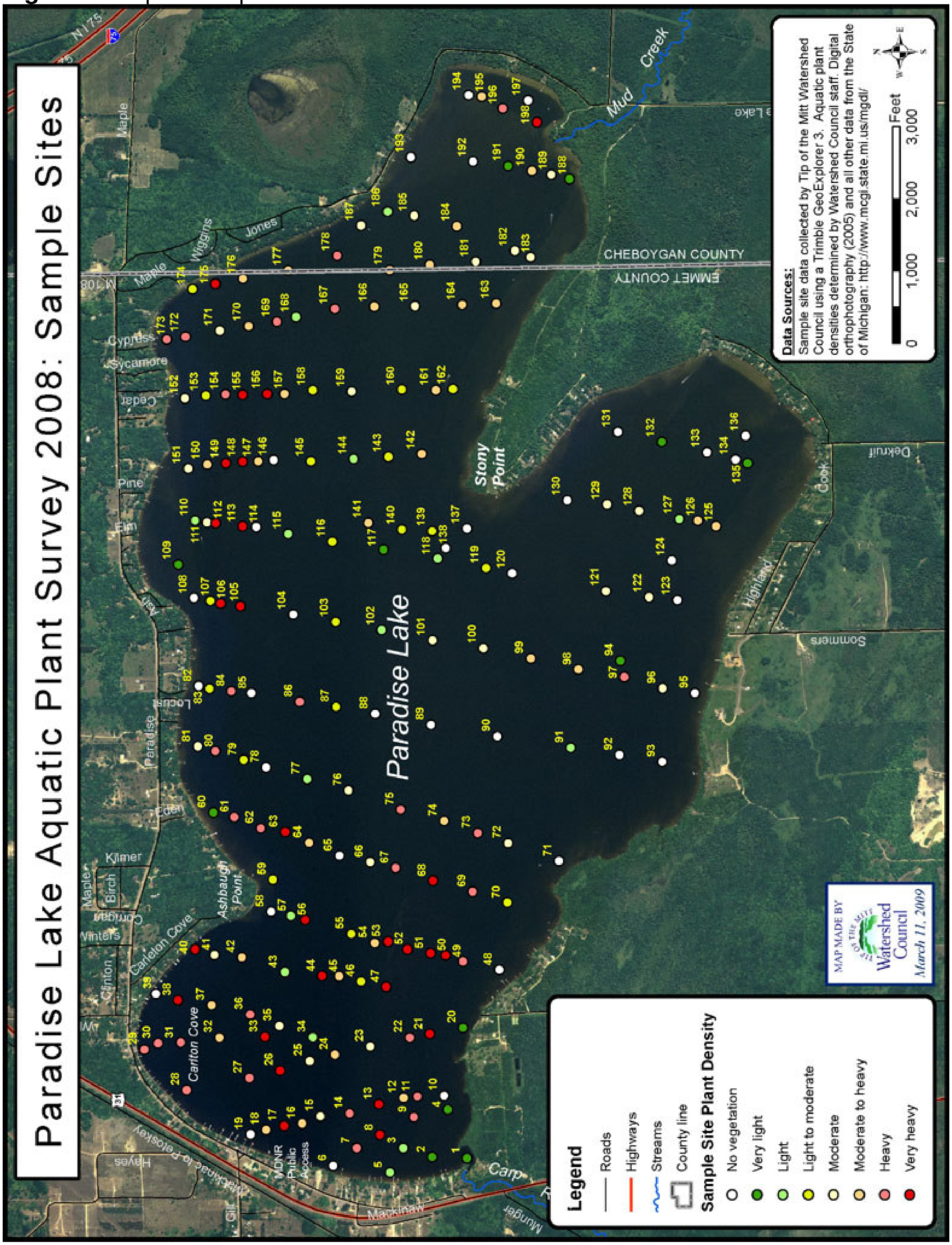
Due to the Paradise Lake Association's concerns about nuisance aquatic plant growth, particular attention was given during this survey to lake areas with dense plant growth and specifically, areas of dense Eurasian watermilfoil growth. Additional sampling and more-detailed plant community mapping were carried out in areas of dense growth. Therefore, there was some sampling bias toward densely vegetated lake areas.

Documenting aquatic plants at sample sites:

Specimens were collected, identified, photographed and recorded in a notebook at 198 sample sites throughout the lake to document aquatic plant taxa. Sample site locations (Figure 5) were not random, but rather selected with the intent of collecting representative information on all aquatic plant communities currently inhabiting the lake. Transects across the lake were sampled at intervals that varied, depending upon plant community changes that were observable from the surface. In areas where plant communities were not visible, sample sites were selected at regular intervals across the transect. Sampling was also conducted in areas of the lake with no visible plants to confirm the areal extent of plant communities.

At each sample site, the boat was anchored, water depth noted, and GPS data recorded. Water depth was monitored using a Hummingbird depth finder installed on the boat. It should be noted that water depths were not recorded at all sample sites due to equipment failure. The location of each sampling station was recorded using a Trimble GeoExplorer3 GPS unit with a reported accuracy of 1-3 meters.

Figure 5. Map of sample sites on Paradise Lake.



Plant specimens were collected using a sampling device consisting of two garden rake heads fastened together back to back with a length of rope attached. Using the sampling device, multiple throws were made at each site, collecting from all sides of the boat. Sampling continued until the collector was satisfied that all plant taxa present at the site were represented in the sample. Rigorous sampling techniques and effort were employed, but some species may have been missed.

Specimens were identified to the lowest taxonomic level possible and representative samples of each species were laid out and photographed with a slip of paper indicating the number assigned to that site. Taxon density was subjectively determined (in relation to all plant taxa collected in the sample) and recorded as light (L), medium (M), or heavy (H), but also including the sub-categories of very light (VL), medium-light (ML), medium-heavy (MH) and very heavy (VH). Furthermore, overall plant density for the site was subjectively determined and noted using the same categorization system. If a specimen could not be identified immediately, it was stored in a sealed bag and identified later with the aid of taxonomic keys, mounted herbarium specimens, and, if necessary, assistance from other aquatic plant experts. All taxa names, relative taxa densities, overall site density and comments were recorded in a field notebook. If no plants were encountered during sampling, 'no vegetation' was recorded in the field notebook.

To assist in mapping the aquatic vegetation in Paradise Lake, additional photographs were taken to document emergent vegetation. At each sample site located within or adjacent to emergent vegetation, pictures were taken of surrounding areas. Pictures were taken with a Ricoh 500SE digital GPS camera (accuracy = 3-10 meters).

Mapping aquatic plant communities:

Additional data were collected to improve the accuracy of delineations between distinct plant communities in the lake. Plant communities can be delineated simply by interpolating or extrapolating between sample points. However, the accuracy of such delineations can be greatly improved by noting and mapping precise locations where one plant community type ends and another begins.

During sampling, details observed about aquatic plant communities at or near the sample sites were recorded in the field notebook. Plant communities that were visible from the boat were described in terms of species composition, areal extent, shape, and density. Changes in plant communities between sample sites and the absence of vegetation in any direction were also noted.

Distinct submerged aquatic plant beds and emergent vegetation were mapped with a GPS. Where feasible, the perimeter of submerged plant beds was followed as closely as possible in the boat and GPS data collected at major vertices to develop polygons representing the plant beds. Emergent plants growing directly along the shoreline were frequently mapped at an offset distance that was recorded in the GPS unit. Plant specimens were not collected during this portion of the community line mapping.

In spite of sampling at 198 sites and subsequent community line mapping, some small or isolated plant communities could have been missed. Plants were not sampled between sites in survey transects and plant community mapping may have not occurred in those areas either if conditions did not allow. Upon several occasions, plant community mapping was impeded by poor visibility, whether from wave turbulence, turbidity, or simply water depth and attenuation of sunlight.

Data processing and map development:

GPS data collected with the Trimble GeoExplorer3 were post-processed and exported into a GIS file format using GPS Pathfinder Office 3.10 software. Two GIS data layers were developed using the field GPS data collected with the Trimble; a point layer using the GPS data collected at sample sites and a polygon layer using a combination of information collected at sample site points and plant community mapping line data. Where possible, polygons were developed directly from line features mapped with GPS in the field. Otherwise, polygons were created based on data collected at sample sites. All GIS work was performed using the ESRI GIS software package ArcView 9.3.

Digital photographs taken with the Ricoh 500SE GPS camera were processed and developed into a GIS data layer using GPS-Photo Link, Version 3.1.0 Ricoh Edition. Photographs were rotated and light levels adjusted as necessary. The date, time, and location (latitude and longitude in the WGS84 datum) were included when processing the photographs and appear on the “tagged” digital photographic files. Pictures taken with the Sony digital camera (without GPS capabilities) were linked in a GIS to sample site points recorded with the Trimble GPS unit. All photographs taken at sample sites were renamed using the lake name, survey and year, and the sample site number (e.g., the first photograph taken at the first sample site = "ParadiseLake_APsurvey2008_001-0.jpg"). An ESRI shapefile was created to display photographs taken at sample sites using hyperlinks.

Data collected at sample sites and written in the field notebook were entered into a database. A record was entered into the database for each sample site, using the sample site number as the unique identifier. Field data were entered as separate attributes in the database table, including water depth, taxa names and densities, areas of little/no vegetation, overall community density, and comments. Additional columns were added to the database for the number of taxa, the dominant taxa, and the dominant community at each site. Data recorded in the spreadsheet were saved to a *.dbf format and imported into a GIS. The *.dbf file was joined to the sample site GIS point data layer, and then exported to a new GIS point data layer containing all attribute information collected in the field for each sample site. After developing polygons representing plant communities and vegetation types, area statistics for specific plant communities and vegetation types were calculated.

The final products include both maps and statistics generated from digital map layers. All GPS, tabular and photographic data were combined in an ArcView project to develop digital and hard-copy maps. The maps depict sample site locations, plant community density at sample sites, and dominant plant communities in the lake. In addition, the ArcView project file allows GIS users to view photographs taken at sample sites (by clicking on point features at the sample site) as well as all tabular data associated with the site.

RESULTS

Sample site results:

A total of 24 aquatic plant taxa were collected or documented during the survey conducted on Paradise Lake (includes five emergent taxa noted in comments, but not collected: bulrush, cattail, pond-lily, sedge, and sweet gale). Of the 198 locations sampled on the lake, aquatic plants were found at 163 sites (82%) while 35 sites (18%) had little or no vegetation. The number of aquatic plant taxa encountered at a site ranged from zero to 13 with an average of 5.0 taxa per sample site. Only one invasive species was encountered during this survey: Eurasian watermilfoil.

Eurasian watermilfoil and slender naiad were the most commonly encountered species; collected at approximately 64% and 61% of sites respectively (Table 2). Seven other species were collected at 50 sites or more and considered common; including elodea, whitestem pondweed, common bladderwort, eel-grass, Robbins' pondweed, fine-leaved pondweed, and muskgrass. Only three plant species occurred uncommonly, which was defined as occurring at 10 to 50 sites and the remaining seven taxa were rarely collected (occurring at fewer than 10 sites).

Eurasian watermilfoil and slender naiad occurred as dominant or co-dominant plants at the greatest number of sample sites (at ~33% of sites, Table 3). Muskgrass was the next most dominant plant followed by several pondweed species, eel-grass, and common bladderwort. All other taxa were dominant or co-dominant at less than 10% of sample sites.

Typical for lakes in this region, the pondweed family (*Potamogetonaceae)* was the most speciose (i.e., had the greatest number of species). A total of 10 pondweed species were documented in Paradise Lake during this survey. Pondweeds were also observed growing at very heavy densities, such growth commonly reaching the surface and often adjacent to or intermixed with similarly heavy Eurasian watermilfoil growth.

Overall aquatic plant community densities were generally heavy at sample sites. Approximately 44% of sample sites had aquatic plant community densities that fell into the heavy category (MH, H, and VH) as compared to light (VL, L, and LM) at 24% of sites (Table 4). The remainder either fell into the moderate category (14%) or had no vegetation (18%). Sample sites with heavy or very heavy plant densities were concentrated in the western basin and along the northern shore (Figure 5).

Table 2. Aquatic plant species occurrence at sample sites.

Genus and species	Common Name	# of sites	Occurrence*
Myriophyllum spicatum	Eurasian watermilfoil	127	Common
Najas flexilis	Slender naiad	121	Common
Elodea canadensis	Elodea	105	Common
Potamogeton praelongus	Whitestem pondweed	96	Common
Utricularia vulgaris	Common bladderwort	94	Common
Vallisneria americana	Eel-grass	85	Common
Potamogeton robbinsii	Robbins' pondweed	74	Common
Potamogeton pusillus	Fine-leaved pondweed	73	Common
Chara spp.	Muskgrass	64	Common
Potamogeton richardsonii	Richardsons' pondweed	48	Uncommon
Megalodonta beckii	Water marigold	32	Uncommon
Potamogeton gramineus	Variable-leaf pondweed	28	Uncommon
Potamogeton amplifolius	Broad-leaved pondweed	9	Rare
Myriophyllum heterophyllum	Variable-leaf watermilfoil	6	Rare
Potamogeton strictifolius	Narrow-leaf pondweed	5	Rare
Potamogeton epihydrus	Ribbonleaf pondweed	4	Rare
Potamogeton natans	Floating-leaf pondweed	4	Rare
Potamogeton zosteriformis	Flat-stem pondweed	3	Rare
Ceratophylum demersum	Coontail	1	Rare

**Occurrence categories determined by Watershed Council staff based on natural breaks: 1-10 = rare, 11-50 = uncommon, and 51+ = common.*

Table 3. Aquatic plant dominance at sample sites

Aquatic Plant Species	Common Name	Number of sites where dominant*	Percent of sites where dominant†
Najas flexilis	Slender naiad	54	33.1
Myriophyllum spicatum	Eurasian watermilfoil	53	32.5
Chara spp.	Muskgrass	36	22.1
Potamogeton praelongus	Whitestem pondweed	25	15.3
Potamogeton robbinsii	Robbins' pondweed	23	14.1
Vallisneria americana	Eel-grass	21	12.9
Potamogeton pusillus	Fine-leaved pondweed	20	12.3
Utricularia vulgaris	Common bladderwort	18	11.0
Potamogeton gramineus	Variable-leaf pondweed	12	7.4
Elodea canadensis	Elodea	11	6.7
Potamogeton richardsonii	Richardsons' pondweed	6	3.7
Potamogeton strictifolius	Narrow-leaf pondweed	2	1.2
Potamogeton natans	Floating-leaf pondweed	2	1.2
Potamogeton amplifolius	Broad-leaved pondweed	1	0.6

*Number of sites where species was dominant or co-dominant
†Excludes sites where no vegetation was found.

Table 4. Aquatic plant densities at sample sites.

Density Category	Number of sites	Percent of sites
No Vegetation	35	17.68
Very Light (VL)	12	6.06
Light (L)	15	7.58
Light-moderate (LM)	20	10.10
Moderate (M)	28	14.14
Moderate-heavy (MH)	32	16.16
Heavy (H)	29	14.65
Very Heavy (VH)	27	13.64
TOTAL	198	100.00

Plant Community mapping results:

After compiling data from sample sites and plant community delineations, maps were developed to display the aquatic plant communities of Paradise Lake. Map layers depict lake areas covered by the various dominant plant community types observed during the survey, as well as growth densities within these communities. GIS data layers developed to create the maps include statistics regarding the type, extent, and density of the plant communities.

The aquatic plant community map layer revealed that 826 of the 1,947 acres (~42%) of Paradise Lake contained little or no aquatic vegetation (Table 5 and Figure 6). Vegetated areas were divided into broad categories of emergent vegetation (bulrush, cattails, pond-lilies, etc.), submergent vegetation (muskgrass, pondweed, naiad, etc.), and a mix of the two. Of the 1,121 acres of Paradise Lake containing aquatic vegetation, the vast majority, approximately 97%, consisted of submergent vegetation, with the remainder being emergent vegetation.

Table 5. Lake and vegetated area statistics.

Lake and Vegetation	Surface Area (acres)	Percent of Total Surface Area
Paradise Lake	1946.88	100.00
Little or no vegetation	826.23	42.44
Aquatic vegetation:	1120.65	57.56
a. Emergent vegetation	27.46	2.54*
b. Submergent vegetation	1091.02	97.36*

*refers to percent of surface area with aquatic vegetation (i.e., 1121 acres).

Muskgrass and pondweeds communities were the most extensive in Paradise Lake, each covering over 180 acres (Table 6). Mixed submergents, eel-grass, naiad, watermilfoil, and a naiad/pondweed mix were the next most prevalent dominant plant community types in terms of areal extent, covering from 100 to 150 acres each. All other dominant community types covered less than 50 acres each.

Table 6. Dominant aquatic plant community types and acreage.

Dominant Community	Acreage	Percentage
Little or no vegetation	826.23	42.44
Muskgrass Mix	185.65	9.54
Pondweed Mix	181.77	9.34
Mixed Submergents	144.86	7.44
Eel-grass Mix	134.65	6.92
Naiad Mix	133.18	6.84
Watermilfoil Mix	114.56	5.88
Naiad and Pondweed Mix	110.18	5.66
Pondweed and Watermilfoil Mix	41.74	2.14
Bulrush	25.50	1.31
Naiad and Watermilfoil Mix	15.60	0.80
Elodea and Watermilfoil Mix	13.91	0.71
Muskgrass and Naiad Mix	11.38	0.58
Elodea Mix	5.66	0.29
Mixed Emergents	1.16	0.06
Pond-lily	0.85	0.04
TOTAL	1946.88	100.00

The aquatic plant communities of Paradise Lake predominantly contained moderately dense growth with over 600 acres in the LM, M, and MH categories (Table 7). The areal extent of communities with heavy to very heavy plant densities exceeded 400 acres and just over 100 acres possessed light or very light growth. Similar to sample site densities, aquatic plant community growth density was highest in the western basin and along the northern shore (Figure 7).

Eurasian watermilfoil dominated plant communities in several locations on the west end, at a few locations along the eastern end of the northern shore, and in an isolated pocket in the south-central part of the lake (Figure 8). The combined acreage of Eurasian watermilfoil-dominated beds was 115 acres: 76 acres in the western basin, 38 acres in the northeast, and less than one acre in the south. The largest beds include that on the west end that extends north from the MDNR launch up to Rollo Road (~30 acres); another bed beginning near the MDNR launch and extending approximately ¾ of a mile to the east (~43 acres), and a narrower, but slightly longer bed along the north shore starting at Poplar Street and continuing east past Cypress Street (~27 acres).

Table 7. Aquatic plant community densities.

Density Category	Acres	Percent
No vegetation	826.23	42.44
Very Light	16.43	0.84
Light	85.16	4.37
Light to Moderate	229.00	11.76
Moderate	219.74	11.29
Moderate to Heavy	160.37	8.24
Heavy	264.00	13.56
Very Heavy	145.97	7.50
TOTAL	1946.88	100.00

Eurasian watermilfoil was a co-dominant plant together with elodea, naiad or pondweeds in plant communities scattered throughout the lake (Figure 8). As a co-dominant, Eurasian watermilfoil was documented in 71 lake acres. In areas categorized as “mixed emergents”, which consisted of multiple dominant species, Eurasian watermilfoil was one of the dominant species in an additional 24 acres.

Pondweeds dominated and exhibited heavy-density growth in several areas in Paradise Lake. White-stem and Robbins’ pondweeds commonly dominated plant communities (Table 3) and co-occurred with heavy-density Eurasian watermilfoil growth. Fine-leaved pondweed also dominated plant communities and was found at heavy densities, but generally did not co-occur with heavy-density Eurasian watermilfoil growth. Heavy-density pondweed growth was found mixed in or, more commonly, adjacent to most of the dense Eurasian watermilfoil beds in the lake. The heaviest density pondweed beds were found in the north and south ends of the western basin as well as along the northern shoreline from Ashbaugh Point to the northeastern corner of the lake (Figures 6 and 7) .

Figure 6. Map of aquatic plant community types in Paradise Lake.

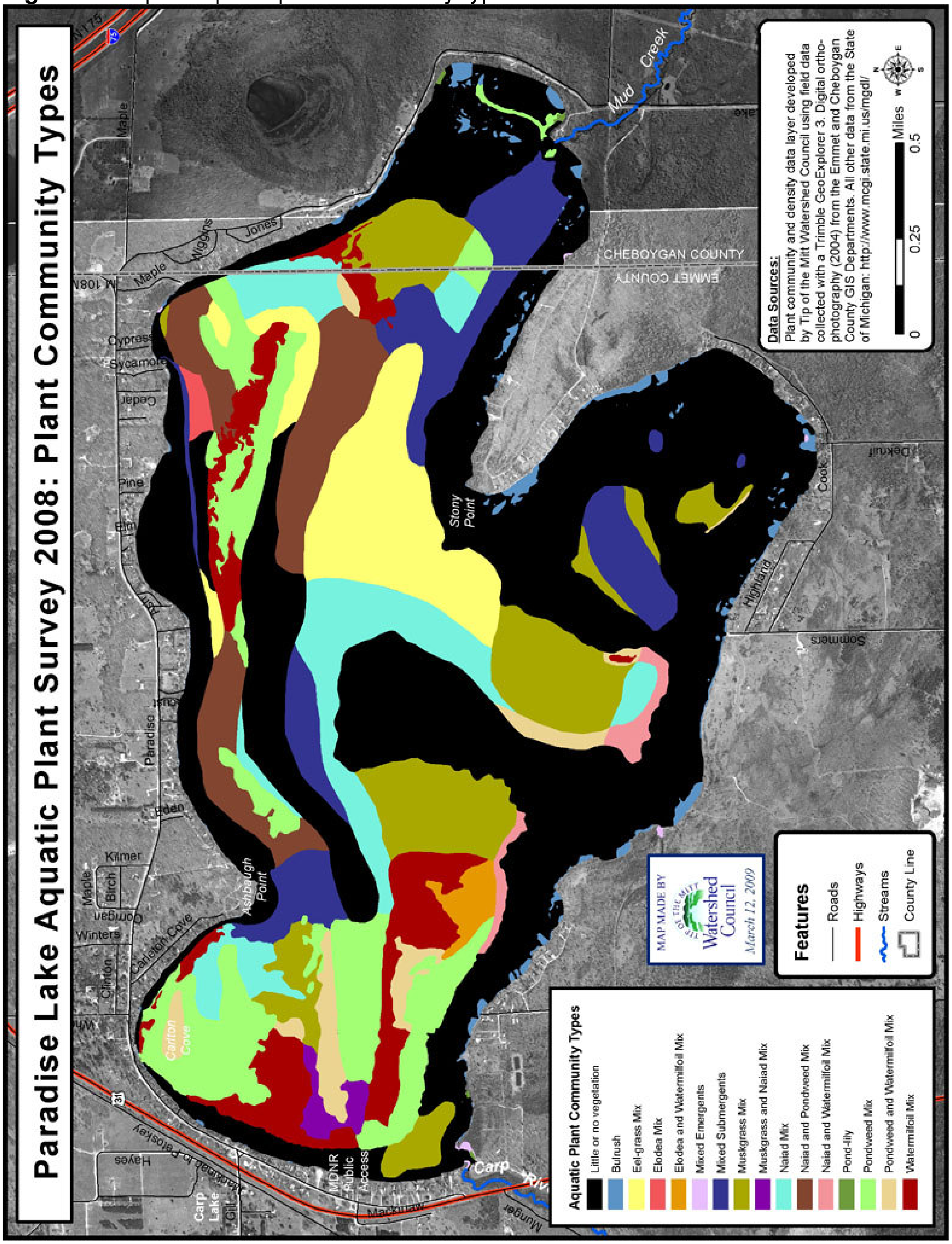


Figure 7. Map of aquatic plant community densities in Paradise Lake.

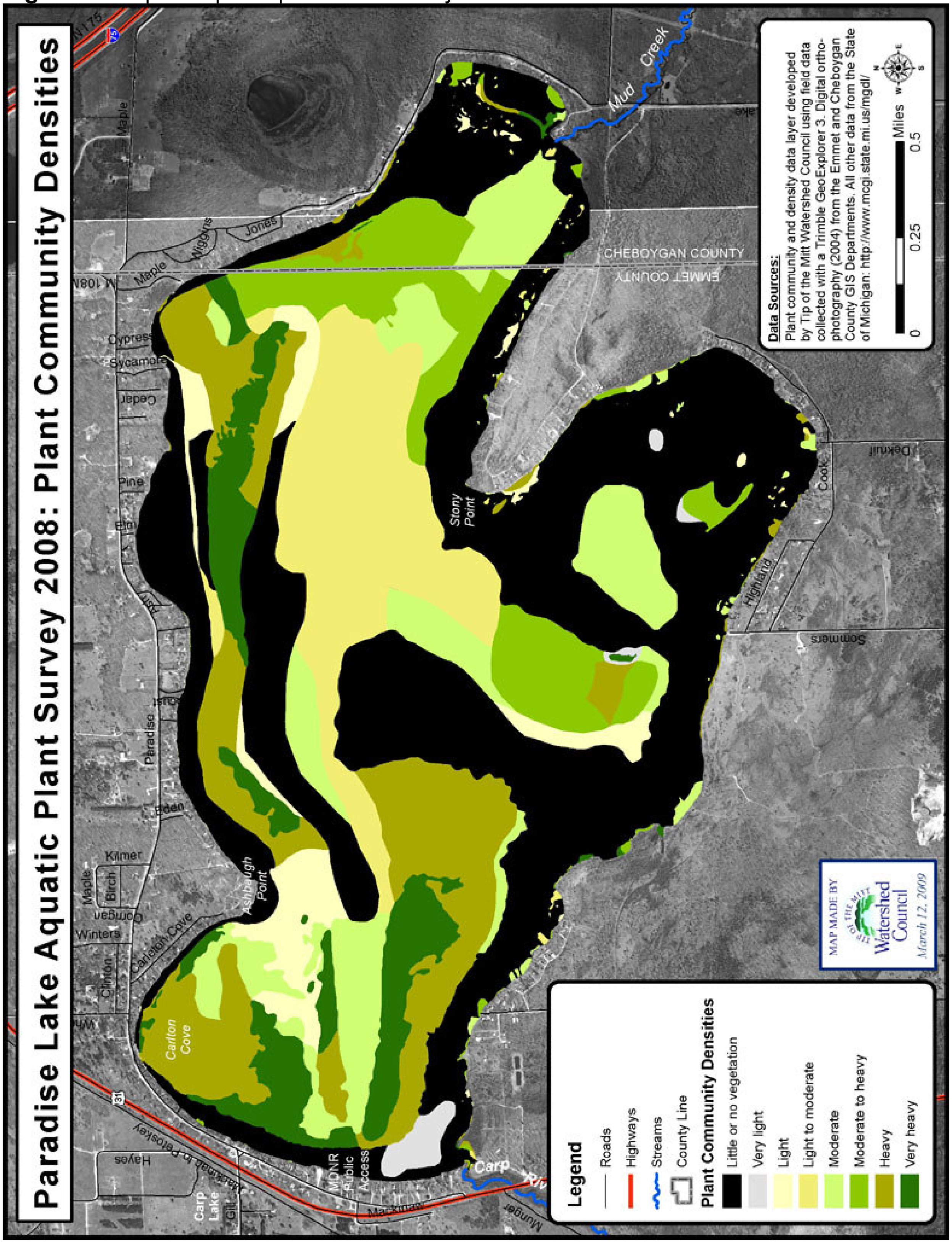
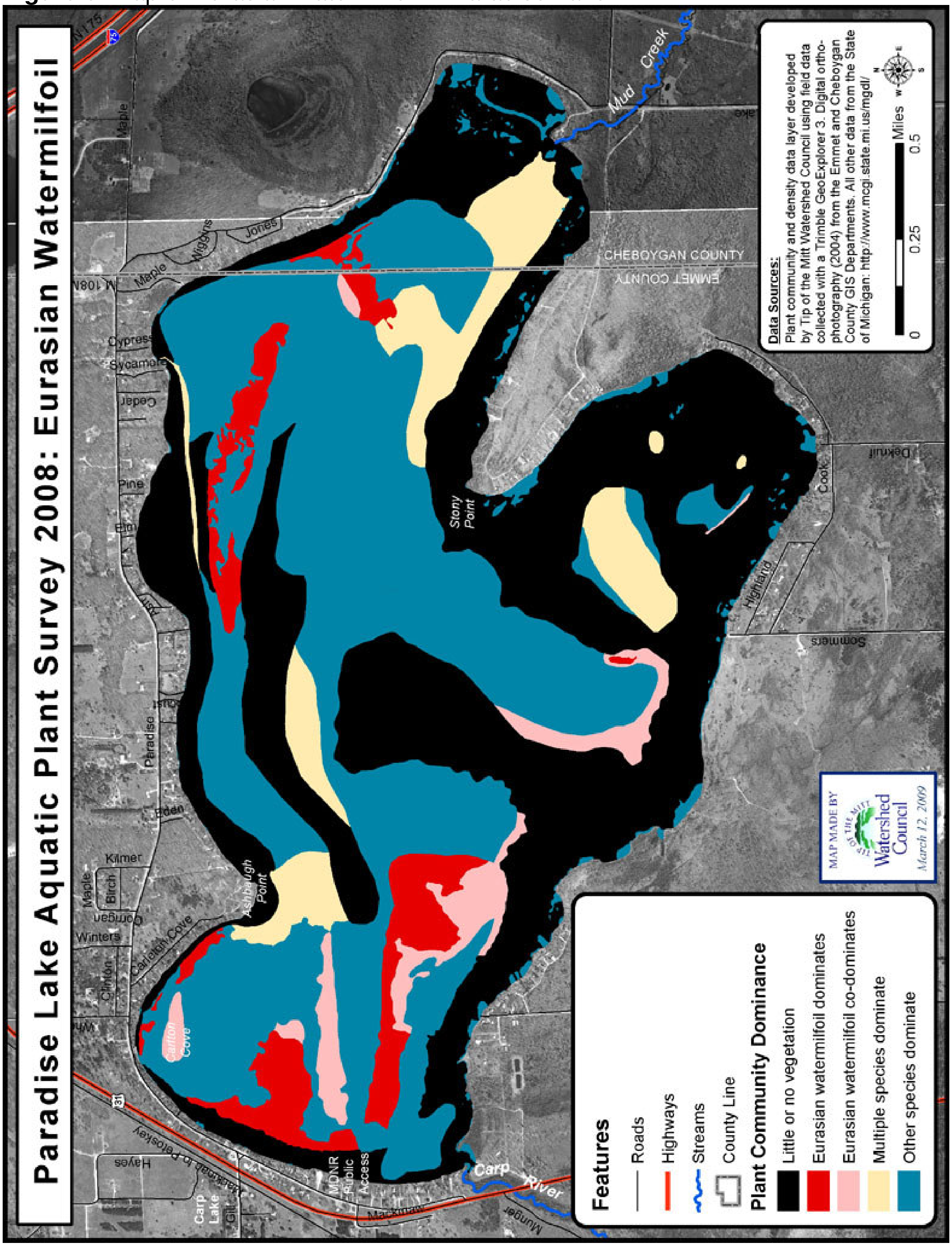


Figure 8. Map of Eurasian watermilfoil in Paradise Lake.



DISCUSSION

General

Survey results revealed that large areas of Paradise Lake contain little or no vegetation and that a diverse assemblage of native plant species exists in the lake. In terms of surface area, over 40% of the lake contains little or no vegetation. In vegetated areas, a total of 24 aquatic plant taxa were documented during the survey, which ranks Paradise Lake in the middle for aquatic plant diversity in lakes surveyed by the Watershed Council (Table 8). However, the averaged diversity across sampling sites in Paradise Lake (5 taxa/site) was among the highest.

Table 8. Aquatic plant survey statistics from area lakes.

Lake name	Acreage	Maximum depth (ft)	Percent with vegetation	Number of total taxa	Number of taxa/site
Black	10,133	50	13%	32	3.7
Long	388	61	9%	18	3.8
Millecoquin	1,116	12	95%	20	6.0
Mullett	17,205	144	19%	42	3.1
Paradise	1,947	17	58%	24	5.0
Wycamp	689	7	83%	35	4.9

Generally, water depth and prevailing winds are key determinants of vegetated versus non-vegetated lake areas, which to some extent are apparent in Paradise Lake. In other, deeper lakes surveyed by Tip of the Mitt Watershed Council, it has been found that aquatic plants are usually limited to 20 feet of depth and less. In the case of Paradise Lake, the maximum depth is less than 20 feet, but regardless, a sizable portion of the deep trough running from east to west in the northern half of the lake contained little or no vegetation (Figure 7). As evidenced in aquatic plant surveys for other lakes, prevailing winds in this region from the northwest tend to create lightly or non-vegetated areas in the eastern and southeastern sides of lakes (as a result of wind and wave action). This pattern is also apparent in Paradise Lake, as there were large areas in the ends of the eastern lobes with little or no vegetation. However, areas of little or no vegetation were found in nearshore areas around most of the lake, as well as in an area in the middle of the lake extending from the south shore. These inconsistencies point out that other factors beyond depth and prevailing winds contribute to vegetated lake areas, such as substrate types, nutrient availability, water clarity, water currents, and more.

Although a large portion of the lake area contains little or no vegetation, approximately half of the vegetated lake area consists of heavy-density plant growth (Table 7). Heavy to very heavy plant growth was documented primarily in the western basin and in a somewhat narrow swath along the northern shore extending from Ashbaugh Point down to the northeast shore near Wiggins Road (Figure 8). Areas of heavy plant growth coincide roughly with those documented in a 1996 aquatic plant survey of Paradise Lake conducted by Tip of the Mitt Watershed Council (Appendix A).

Notably, the 1996 and 2008 aquatic plant surveys documented heavy Eurasian watermilfoil growth in roughly the same areas, but there were distinct differences in the extent of growth between the two surveys. The large beds of Eurasian watermilfoil mapped out in 2008 were also present in 1996: the two beds in the western basin extending north and east from near the MDNR boat launch and the bed along the northern shore of the lake. However, the lengths of the east-to-west beds in the western basin and along the northern shore in 2008 were reduced as compared to 1996.

In 1996, the bed in the southwest extended farther east toward the southeast lobe of the lake and the bed along the northern shore extended farther west past Ashbaugh Point. In fact, in 2008 the Eurasian watermilfoil-dominated area along the northern shore was only half the length of what was indicated on the map from the 1996 survey. Heavy Eurasian watermilfoil and whitestem pondweed growth were grouped together in the 1996 survey. However, vegetation surveys conducted by EnviroScience, Inc. in 2000 and 2001 showed a dramatic decrease in Eurasian watermilfoil in these same areas: south of Ashbaugh Point and in the south-central part of the lake. Furthermore, grouping heavy Eurasian watermilfoil and pondweed growth together in the 2008 data still shows a reduction in the length of these beds over time.

New pockets of Eurasian watermilfoil were documented in the 2008 survey along the northern edge of Carlton Cove, in the northeast corner to the south of Jones Road, and in isolated areas in the south-central and southeast corner of the lake (to the southwest and south of Stony Point). These beds were generally small, accounting for a small portion of the total watermilfoil growth. The small beds in new areas accounted for less than 16 acres, which is approximately 14% of the Eurasian watermilfoil-dominated areas. Sampling intensity varied between the two surveys, such that some of these beds may have been overlooked in 1996.

Events and factors affecting plant communities:

Following the 1996 survey, a total of 14,300 weevils were stocked from 1998 to 2000, which helped control problematic Eurasian watermilfoil growth for several years. Follow-up surveys in 2000 and 2001 showed heavy damage to Eurasian watermilfoil beds including the virtual disappearance of beds to the south of Ashbaugh Point and in the south-central area of the lake (EnviroScience, Inc., 2001). Although surveys were not conducted in the interim, little was heard about nuisance Eurasian watermilfoil or other problematic aquatic plant growth until 2006. In 2004, Eurasian watermilfoil growth was reported by lake association members to be at an all-time low (since treatment began in 1998). Starting in 2006, residents noted a resurgence in dense aquatic plant growth, though samples collected from dense-growth areas and delivered to the Tip of the Mitt Watershed Council office for identification were found to be pondweed species. It was not until 2007 that a strong resurgence in Eurasian watermilfoil growth was reported.

Considering ecosystem dynamics and predator versus prey relationships, the weevil populations may have outgrown their food supply around 2004, overgrazed, and then conceivably experienced a population crash due to an inadequate forage base (i.e., not enough watermilfoil to feed upon). During surveys conducted prior to stocking additional weevils in Paradise Lake in the summer of 2008, weevils and damage to Eurasian watermilfoil plants indicative of weevils were observed. Thus, it is potentially just a matter of time before the weevil population increases to the point where they again effectively control Eurasian watermilfoil growth.

Human activity impacts all aspects of the lake ecosystem, from fisheries to phytoplanktonic algae blooms to aquatic plant growth. Recreational pursuits, such as boating, damage aquatic plants and can lead to the introduction of invasive species (i.e., non-native or exotic species). Landscape development along the shoreline and throughout the watershed augments plant growth by adding excess nutrients to the water from sources such as fertilizers, stormwater, and septic systems.

The impact of invasive species introduced by humans is possibly the most serious type of ecosystem disruption. Non-native species have the potential to cause fundamental changes in an aquatic ecosystem, whether through predation on native species, displacement of native species, or disruption of the natural food chain. There are two invasive species that are particularly noticeable and problematic in Paradise Lake: Eurasian watermilfoil and zebra mussels. These invasives were probably introduced unintentionally, hitching a ride on a boat or boat trailer from a nearby lake.

Eurasian watermilfoil has been known to be in Paradise Lake for at least 13 years, but zebra mussels have only recently become abundant. Zebra mussels disrupt ecosystems due to their feeding habits. They are voracious filter feeders, filtering phytoplanktonic algae (minute, free-floating algae) from the water and in so doing, give a competitive edge to other types of algae and to higher aquatic plants like watermilfoil or pondweed. In lakes infested by zebra mussels, water quality monitoring data show an increase in water transparency, which allows sunlight to penetrate deeper into the water and thus, stimulate aquatic plant growth. The reduction in phytoplanktonic algae biomass as a result of zebra mussel feeding also has the effect of increasing nutrient availability for higher aquatic plants, as there is less competition for nutrient uptake.

Interestingly, the noted increase in zebra mussel abundance coincides with the recent resurgence of nuisance aquatic plant growth in Paradise Lake. However, water clarity data from the Tip of the Mitt Watershed Council Volunteer Lake Monitoring program have not shown a marked change (Appendix B). Considering that zebra mussels have only recently been found in abundance in Paradise Lake, it might be too early to yet detect a change in water clarity. Furthermore, changes in water clarity may not be readily apparent due to the tannins in Paradise Lake that give the water a brown tea-like color. Therefore, zebra mussel feeding might allow sunlight to penetrate deeper into the water column, but may not be detectable with water clarity monitoring methods currently used; further study is needed. Chlorophyll-a data, also collected in the Volunteer Lake Monitoring program, provides a measure of algal biomass. Chlorophyll-a concentrations in Paradise Lake dropped steadily from 2002 to 2008, which may have been caused by zebra mussels (Appendix B).

Nutrient availability is a determining factor in aquatic plant growth and invariably influenced by human activity along the Paradise Lake shoreline and in its watershed. A shoreline survey sponsored by the Paradise Lake Association and conducted by Tip of the Mitt Watershed Council during 2002 documented shoreline conditions that had the potential to adversely impact water quality, with a particular focus on nutrient pollution. *Cladophora* growth, a filamentous green alga that serves as a bio-indicator of nutrient pollution, was observed at 73 shoreline properties (nearly 1/5 of all shoreline properties). Most properties with Cladophora growth in the 2002 survey were on the north side of the lake, with an extensive concentration in Carlton Cove from Gill Road to near Ashbaugh Point and another smaller concentration between Pine and Elm Streets (Appendix C). In accordance with those results, heavy-density plant growth was observed in the lake in both of these areas during the 2008 plant survey. Noticeably, new areas of heavy-density Eurasian watermilfoil and pondweed growth appeared in the northern end of Carlton Cove between the 1996 and 2008 surveys. Shoreline nutrient pollution accelerates aquatic plant growth, whether from fertilizers, malfunctioning septic systems, erosion, stormwater or other sources.

Aquatic plant control options:

In general, there are four major approaches to aquatic plant management, as well as combinations of these. One option is to do nothing and let nature take its course. Otherwise, options for controlling problematic aquatic plant growth consist of chemical, physical or biological treatment. Chemical control would entail the application of herbicide to kill or suppress growth of nuisance plants. Physical control involves plant removal, dredging, lake drawdown or barrier installation. Biological control is accomplished by introducing another living organism that feeds upon or by some other means, disrupts the life cycle of the target species.

Aquatic plant control options should be carefully evaluated, weighing the positive against the negative aspects of each one. Following the wrong road could lead to even greater problems. Aquatic plants that seem like a nuisance to a swimmer or boater may be a sanctuary for small fish, macroinvertebrates and other aquatic life. Drastic alteration of the aquatic plant community could have far-reaching and devastating impacts on fisheries and the entire ecosystem. The information provided in the following section is summarized in an aquatic plant control options matrix (Appendix D).

Natural control

Aquatic plant communities and growth or density within these communities fluctuates naturally over time. There may be periods of heavy nuisance growth in a given area that are followed by periods of little to no growth. Sometimes, simply being patient and letting nature take its course is the best option.

However, natural control may not be appropriate for lakes that are or have become 'unnatural.' Human-made lakes, lakes being polluted from excessive urban or agricultural runoff, and lakes suffering from the introduction of invasive species are all examples of unnatural lakes. In instances like these, not taking action to control aquatic plant growth would likely result in further problems. Nevertheless, solutions could consist of indirect methods, such as changing human behavior and practices (e.g., reducing fertilizer application or properly maintaining septic systems), as opposed to direct control of plant growth.

There are a variety of resources for determining natural fluctuations in the aquatic plant community on a given lake. One of the best is people; particularly individuals who have lived on or near the lake for a long period of time and can provide the "big picture". Other resources include: surveys and reports from regulatory agencies such as the DNR, research reports from universities, and surveys and reports from other organizations or companies working in water resource management. Even archive newspapers and other forms of media may provide clues to historical trends in aquatic plant growth in the lake. Unfortunately, conducting background research takes a lot of time and effort and may not provide reliable results.

Chemical control

There are many chemicals on the market that are used to control aquatic plants. Some of the most commonly used include endothall, glyphosate, copper-sulfate and diquat. Some herbicides, such as fluridone and 2-4.D, selectively control Eurasian watermilfoil and a limited number of other species when applied at proper rates. The MDEQ maintains a list of approved herbicides and target species (Appendix D). Research by MDEQ staff has shown that herbicides applied to surface water can migrate into shallow lakeshore groundwater (Lovato et al. 1996).

Herbicide application has the potential to indirectly stress or kill aquatic organisms. Following herbicide treatment, dead plant material settles to the lake bottom and is consumed by aerobic decomposers. Depending on the amount of dead plant material, decomposers can substantially reduce or even deplete the dissolved oxygen stores in a localized area. Shallow lakes are particularly vulnerable to this problem. Depleted or low dissolved oxygen levels will stress or kill fish and most other organisms living in the aquatic environment. Fish have the ability to rapidly move to other areas of the lake with higher dissolved oxygen concentrations, but smaller less mobile organisms, such as midges, mayflies, and snails cannot move as quickly and are more likely to succumb to localized dissolved oxygen deficits.

Chemical control creates the distinct possibility of long-term application; year after year, perhaps indefinitely into the future. Although often less expensive than physical or biological control in the short-term, long-term chemical control costs may reach or surpass that of other methods. Of greatest concern, though, is that some chemicals, particularly copper from copper-sulfate, build up in the environment with continual application and can reach levels that are toxic for aquatic organisms (Oleskiewicz 2002).

Whole-lake herbicide treatment has been used on some lakes that are heavily infested with Eurasian watermilfoil. However the same drawbacks, which are discussed by Wisconsin DNR staff in a 2005 issue of Lake Tides (Hauxwell 2005), should apply. If the Lake Association opts for any type of chemical control, a permit through the MDEQ will be required.

Physical control

Physical aquatic plant control can be accomplished through various means including: manual cutting/removal, mechanical cutting/removal, dredging, and barrier installation. Manual removal is performed by pulling or cutting aquatic plants by hand or with hand tools. Mechanical cutting/removal uses machines to cut and remove aquatic plants. Dredging deepens an area by removing soft bottom sediments, essentially reducing habitat for aquatic plants by reducing the lake bottom area that receives sunlight. The remaining option is to install fabric benthic barriers along the lake bottom, which blocks sunlight and prevents plant growth. Most of these methods require a permit from MDEQ.

Manual aquatic plant removal is an age-old technique that is commonly applied in small areas. You simply get into the water and pull plants (and roots) out by hand or use a tool, such as a scythe to cut plants or a rake to remove plants. Advantages of this method include low costs, the ability to remove specific species, and long duration of control if the entire plant is removed. The disadvantages for manual removal are that it is labor intensive, time consuming, creates some localized turbidity, and requires diving equipment in deep areas. In general, this method is only feasible for a small area.

Mechanical cutting and removal is a method commonly applied in large areas, using equipment that functions like a lawn mower. Like lawn mowers, some systems simply cut the plants while others cut and collect. Aquatic plant cutters range from simple systems that can be attached to a small boats (14'+ of length) to specialized cutting boats. The cutters typically cut to a depth of 4-7 feet. Aquatic plant harvesters are large machines that cut and collect aquatic plants. Harvesters typically cut a swath 6 to 20' wide and 5 to 10 feet deep, removing the plants from the water and storing them for later disposal.

There are a number of considerations pertaining to cutters and harvesters. As with mowing a lawn, aquatic plants may need to be cut several times per season. Some species are difficult to cut, while others fragment when cut and spread to (and colonize) other parts of the lake. Watermilfoils fragment when cut and therefore, should not be controlled using cutters or harvesters. Sediments may be loosened when using cutters and harvesters in shallow areas of lakes with soft sediments. Loosened sediments that become suspended in the water column will clog fish and invertebrate gills as well as smother and reduce habitat of small aquatic organisms when resettling.

Dredging is sometimes used as a method for aquatic plant control, but has many drawbacks. Although aquatic plants are removed during dredging operations, long-term plant control is achieved by deepening an area sufficiently to reduce lake bottom area suitable for plant growth. Aquatic plant surveys conducted by Watershed Council staff indicate that aquatic plants usually exist in lake areas up to approximately 20 feet in depth, though dense aquatic plant growth generally disappears in depths that exceed 15 feet. Even dredging small areas to a depth of greater than 15 feet would be a costly and time-consuming operation. Plant removal as a result of dredging has the potential to destabilize lake bottoms and even cause shoreline erosion as roots hold sediments in place and plant stems/leaves absorb wave energy and currents. Furthermore, dredging stirs up sediments and may cause nutrients and other contaminants to be released into the water column. Loosening sediments has the same biological consequences as described above for harvesters.

Diver dredging is an aquatic plant control technique that utilizes SCUBA divers to remove plants using hoses and suction. This method is particularly useful for removing aquatic plants from around docks and other areas that are difficult to access. Diver dredging also allows for selective removal of target species. However, the procedure is not 100% effective as root masses are not always removed. As with other forms of dredging, diver dredging is expensive and has the same negative impacts on lake ecosystems, though to a lesser degree as mostly plant material and little sediment is removed.

Benthic barriers are installed in limited areas to control patches of aquatic nuisance plant growth or to eliminate plants from swimming areas. Benthic barriers reduce or eliminate aquatic plant growth due to compression and lack of sunlight. Materials ranging from burlap to synthetics have been used as benthic barriers. Barrier installation is accomplished more easily in late fall, winter, or early spring, when plant growth is minimal. It is extremely important to securely fasten barriers to the lake bottom as gases building up underneath will cause the barrier to bulge and rise. Aquatic plant control will only last as long as the barrier remains intact or until enough sediment has been deposited on top of the barrier to allow for plant growth.

Free-floating aquatic plant species, such as coontail, are not controlled by barriers. Other plants growing near the barriers, such as watermilfoils, are able to send out lateral shoots and inhabit areas where barriers have been installed. Spawning fish and other aquatic organism inhabiting lake bottom areas covered by barriers may be affected. Benthic barriers are susceptible to damage by anchors, fishing gear, harvesters, weather and other factors and must be inspected regularly as they can create safety hazards for navigation and swimming.

Biological control

Biological control of aquatic plants has primarily been used in Michigan to control the growth of two non-native species: Eurasian watermilfoil and purple loosestrife (*Lythrum salicaria*). In both cases, a specific aquatic beetle known to feed upon the invasive plant is stocked in infested areas. The beetle (*Galerucella spp.*) used to control purple loosestrife originates from Europe, but underwent extensive testing before being released in the United States. The beetle (*Euhrychiopsis lecontei*) used to control Eurasian watermilfoil is native to Michigan, due to the presence of native watermilfoils, but feeds preferentially on the exotic watermilfoil. Both of these bio-control agents have been quite successful in controlling growth of the target nuisance aquatic plant species.

The biggest drawback to using biological control is the potential for non-native bio-control agents to proliferate, become a nuisance, and cause ecosystem disruptions. Non-native species should never be introduced as bio-control agents unless approved by regulatory agencies (i.e., MDEQ). The introduction of untested, non-native bio-control organisms can severely alter the native ecosystem.

Bio-control can be expensive in the short-term but cost-effective in the long term. Beyond costs of the bio-control organism, surveys conducted before, during and after stocking to gauge project progress result in additional costs. However, those are periodic costs rather than annual costs.

Biological control can potentially take several years and there is no guarantee that it will be effective. The success of controlling Eurasian watermilfoil using weevils hinges on many factors, including: a sufficient quantity during stocking, an adequate food supply to maintain the population, and recreational impacts (primarily from boats moving through the treatment areas). Furthermore, there is always the potential need for additional stocking in the future if ecosystem equilibrium is disrupted and the invasive aquatic plants gain the upper hand. However, there are many success stories throughout Michigan and the nation using weevils to control Eurasian watermilfoil. Locally, weevils have been very successful in controlling Eurasian watermilfoil growth in Burt Lake in Cheboygan County and Manistee Lake in Kalkaska County.

If successful, biological control provides a long-term solution for target nuisance species without introducing chemicals into the environment, disturbing sediments, or killing other aquatic organisms. Maintenance is minimal, restocking only if the system again becomes imbalanced. In the case of the watermilfoil weevil, the introduction of an exotic species is not an issue as the weevil is native to Michigan's aquatic ecosystems.

Integrated control

Integrated control consists of a mix of any of the previously described methods of aquatic plant control. Some situations may require an integrated approach, as one method may not be suitable for controlling differing types of nuisance aquatic plant growth within a lake. For example, a lake association may opt for stocking weevils to control an area of the lake infested with watermilfoil, while at the same time installing benthic barriers in a public swimming area that is experiencing nuisance native aquatic plant growth.

By taking an integrated approach you get the combined benefits of all methods used, but also the combined problems of all methods. In addition, one method may affect the success of another. For example, cutting aquatic plants may spread plant fragments that recolonize other parts of the lake where other methods like manual removal were employed. Or, widespread chemical treatment destroys the food source that sustains a biological control organism that is being used.

Recommendations:

1. Share the results of this survey. The results of this study should be widely dispersed to get a maximum return on the Lake Association's investment. Sharing the results with members, non-member lake users, government officials, and others will alert the public to problems occurring in the lake and provide information regarding strategies for resolving the problems. If the public fully understands aquatic plant management issues on Paradise Lake, there will be less resistance to proposed solutions. Furthermore, an informed public may result in behavioral changes that benefit aquatic plant management, such as reducing lake nutrient loads and preventing the introduction of additional non-native species.

2. Develop an aquatic plant management plan. The aquatic plant community is a vital component of the aquatic ecosystem, such that good aquatic plant

management translates to good lake ecosystem management. To properly manage aquatic plants in your lake, an aquatic plant management plan should be developed. There are a number of guides available to help your organization develop such a plan, including *Management of Aquatic Plants* by Michigan DEQ, *Aquatic Plant Management in Wisconsin* by University of Wisconsin Extension, and *A Citizen's Manual for Developing Integrated Aquatic Vegetation Management Plans* by the Washington State Department of Ecology. Your organization's decision to have this survey conducted is an important step in creating a management plan.

3. Address nutrient pollution issues. Nutrient pollution can lead to excessive plant growth and should be controlled wherever and whenever possible. Results from the 2002 shoreline survey indicated that nutrient pollution was likely occurring in a few concentrated areas of the lake. A follow-up survey should be conducted to ascertain whether these same areas are still showing signs of nutrient pollution and if there are additional areas where nutrient pollution is occurring. After identifying chronic and new nutrient pollution areas, efforts should be made to determine sources and address any problems found. If a follow-up survey is not currently possible, the lake association is encouraged to contact and work with property owners where nutrient pollution indicators were found in the 2002 survey to address nutrient pollution issues on the Paradise Lake shoreline. In particular, the lake association should work with property owners in Carlton Cove because nutrient pollution indicators were found along an extensive length of this shoreline in the 2002 survey and aquatic plant growth in that area become heavier between the 1996 and 2008 plant surveys. Property owners in this area should be encouraged to properly maintain septic systems, replace old septic systems using outdated technologies (keeping in mind that drainfield soils have a limited ability to accept and treat wastes, normally about 20 to 30 years and that the State requires a 100-feet setback from the water's edge), reduce or eliminate fertilizer use, compost and mulch far from the shoreline, and prevent stormwater from flowing directly into the lake (use greenbelts, rain gardens, grassy swales or other methods for treating the stormwater).

4. Continue using biological methods for controlling excessive Eurasian watermilfoil growth. Heavy-density Eurasian watermilfoil beds were documented in several areas throughout Paradise Lake. From 1998 to 2000 aquatic weevils were released in Paradise Lake, effectively controlling Eurasian watermilfoil growth for several years. The initial success of the weevils, which were stocked at relatively low rates, combined with the fact that they are a completely environmentally safe and potentially long-term solution provides the basis for our recommendation that the Paradise Lake Association continue using biological control to address the resurgent Eurasian watermilfoil problem. The current weevil population can be augmented by making arrangements to purchase and stock additional weevils. Weevils and damage to Eurasian watermilfoil plants indicative of weevils was noted in a 2008 survey, so it may not be necessary to purchase large numbers of weevils to bring the Eurasian watermilfoil back under control. Biological control does require patience as it may take a year or two to be adequately effective. It is possible that the weevil populations will increase on their own in the next few years (without boosting the population) to sufficiently reduce the Eurasian watermilfoil growth. If successful, the initial costs of using biological control and the length of time required to achieve results are easily offset by the positive aspects of using an environmentally safe method. Chemicals will not be introduced into the lake, sediments will not be stirred up, and there will be no unnecessary loss of aquatic life.

5. Preserve the lake ecosystem and natural diversity. Nuisance aquatic plant growth, both native and non-native, is an issue of great concern for many Paradise Lake shoreline residents and recreationalists. Although some plant communities are dominated by just a few species, most of the vegetated lake area contains a vibrant, healthy, and diverse aquatic plant population. According to PhD. Edward Voss, professor emeritus of the University of Michigan and world-renowned plant expert: “Carp Lake [a.k.a. Paradise Lake] has a very rich flora of many kinds of desirable plant species.” With regards to plant management and control options, the lake association should strive to protect the diverse assemblage of plants present in the lake, which are critical to sustaining

a healthy fishery and necessary for maintaining a healthy aquatic ecosystem. In particular, special attention should be given to coontail (*Ceratophyllum demersum*) and variable-leaf watermilfoil (*Myriophyllum heterophyllum*) as these species were encountered rarely during the survey and are dicotyledons, which means they are susceptible to herbicides such as 2,4-D that are commonly used to control Eurasian watermilfoil growth.

6. <u>Await results of Eurasian watermilfoil control efforts before addressing pondweed growth</u>. A number of heavy-density pondweed beds were found in Paradise Lake during the 2008 survey, but were not nearly as prolific as Eurasian watermilfoil beds. Currently, pondweeds are a minor nuisance compared to Eurasian watermilfoil. If heavy-density pondweed beds expand after control methods are applied to reduce Eurasian watermilfoil beds or if they expand independent of Eurasian watermilfoil control efforts, then options for controlling pondweed growth should be examined and thoroughly deliberated.

7. <u>Educate and inform lake users.</u> Human activity in a multitude of forms typically has the greatest impact on a lake's aquatic plant community. Therefore, effectively managing the lake's aquatic plants requires information and education outreach projects that target shoreline property owners, watershed residents and all other lake users. Residents can improve land management practices to reduce nutrient loading (to control excessive plant growth) by establishing naturally vegetated buffers along the shoreline, reducing or eliminating yard fertilizers, and properly maintaining septic systems. Lake associations can help prevent the introduction of non-native species (such as the nuisance plant *Hydrilla* that looms on the horizon) by posting signs and educating members and other lake users. Outreach activities should not be limited to dos and don'ts, but also include general information about aquatic plants and their importance to the lake ecosystem.

8. Regularly survey the aquatic plants of Paradise Lake. To properly manage the aquatic plant community of Paradise Lake, additional aquatic plant surveys should be conducted in the future. Future surveys will provide the Lake Association with valuable data for determining trends over time, evaluating successes or failures of aquatic plant management projects, and documenting the locations and spread of non-native aquatic plant species. Although dependent upon many different variables, surveying the aquatic plant community on a 5-10 year basis is generally sufficient.

LITERATURE AND DATA REFERENCED

Cheboygan County GIS Department. 2004. Digital Orthophotography 1:400. Cheboygan, MI. http://www.cheboygancounty.net/pages/equalization/

Crow, G. E. and C. B. Hellquist. 2000. Aquatic and Wetland Plants of Northeastern North America. The University of Wisconsin Press. Madison, WI.

Emmet County GIS Department. 2004. Digital Orthophotography 1:400. Petoskey, MI. http://www.co.emmet.mi.us/equalization/

Enviroscience, Inc. 2001. Final Progress Report for the Implementation of the MiddFoil® Process of Eurasian Watermilfoil Control to Paradise Lake, MI. Stow, OH. http://www.enviroscienceinc.com

Garling, Donald and H. Wandell. 2006. Nuisance Aquatic Plant Control Using Algaecides and Herbicides for 2006. Michigan State University Extension. East Lansing, MI. http://web1.msue.msu.edu/waterqual/

Gibbons, M. V. and H. L. Gibbons. 1994. A Citizen's Manual for Developing Integrated Aquatic Vegetation Management Plans. Washington State Department of Ecology. Olympia, WA. http://www.ecy.wa.gov/biblio/93093.html

Great Lakes Environmental Research Laboratory. 2009. Aquatic Invasive Species. http://www.glerl.noaa.gov/res/Programs/ais/

Hauxwell, J. K. Wagner, and A. Mikulyuk. 2005. Getting It Right: Whole-lake Herbicide Debate Deserves a Dose of Science. Lake Tides. University of Wisconsin Extension. Stevens Point, WI. http://www.uwsp.edu/cnr/uwexlakes/laketides/

Korth, R. et al.2007. *Aquatic Plant Management in Wisconsin.* University of Wisconsin Extension. Stevens Point, WI. http://www.uwsp.edu/cnr/uwexlakes/ecology/APMguide.asp

Lovato, J. L., B. O. Fisher, and W. E. Brown. 1996. Migration of Aquatically Applied Herbicides from Surface Water to Ground Water. Lansing, MI.

Oleskiewicz, D. 2002. Copper in Our Waterways. Buckeye Basins. Ohio State University Extension. Caldwell, OH. http://ohiowatersheds.osu.edu/newsletter/2002-3.html

Michigan Department of Information Technology, Center for Geographic Information. 2009. Michigan Geographic Data. Lansing, MI. http://www.mcgi.state.mi.us/mgdl/

Michigan Department of Natural Resources. 2009. Inland Lake Maps. Lansing, MI. http://www.michigan.gov/dnr/0,1607,7-153-30301_31431_32340---,00.html

Michigan Department of Natural Resources. 2004. Unpublished fish survey data. Cadillac, MI. http://www.michigan.gov/dnr/

National Oceanic and Atmospheric Administration, Coastal Services Center. 2003. Coastal Great Lakes Land Cover Project. Charleston, SC. http://www.csc.noaa.gov/crs/lca/greatlakes.html

Sportsman's Connection. 2002. Northwestern Michigan Fishing Map Guide. Superior, WI. http://www.sportsmansconnection.com/

Tip of the Mitt Watershed Council. 2003. A Shoreline Survey of Paradise Lake 2003. Petoskey, MI. http://www.watershedcouncil.org/

Tip of the Mitt Watershed Council. 2007. Comprehensive Water Quality Monitoring Program. Petoskey, MI. http://www.watershedcouncil.org/

Tip of the Mitt Watershed Council. 2008. Volunteer Lake Monitoring Program. Petoskey, MI. http://www.watershedcouncil.org/

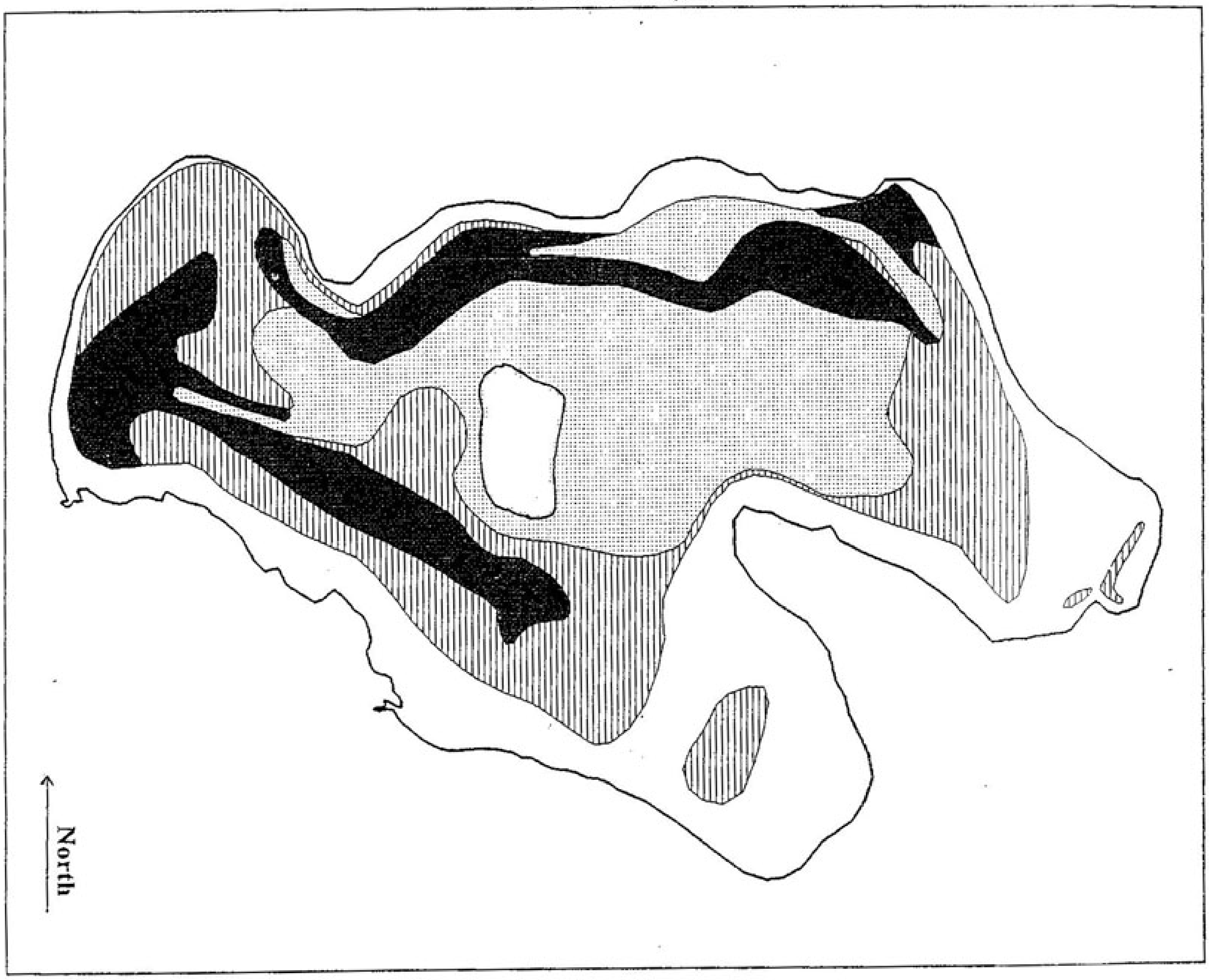
Unites States Geological Survey. 1990. 1/100,000 Topographic Maps. Reston, VA.

USDA Forest Service. 2009. Eastern Region invasive plants, ranked by degree of invasiveness as based on information from States. Milwaukee, WI. http://www.fs.fed.us/r9/wildlife/range/weed/Sec3B.htm

Appendix A: Map from 1996 aquatic plant survey on Paradise Lake.

SUBMERGENT AQUATIC PLANT COMMUNITIES OF PARADISE LAKE

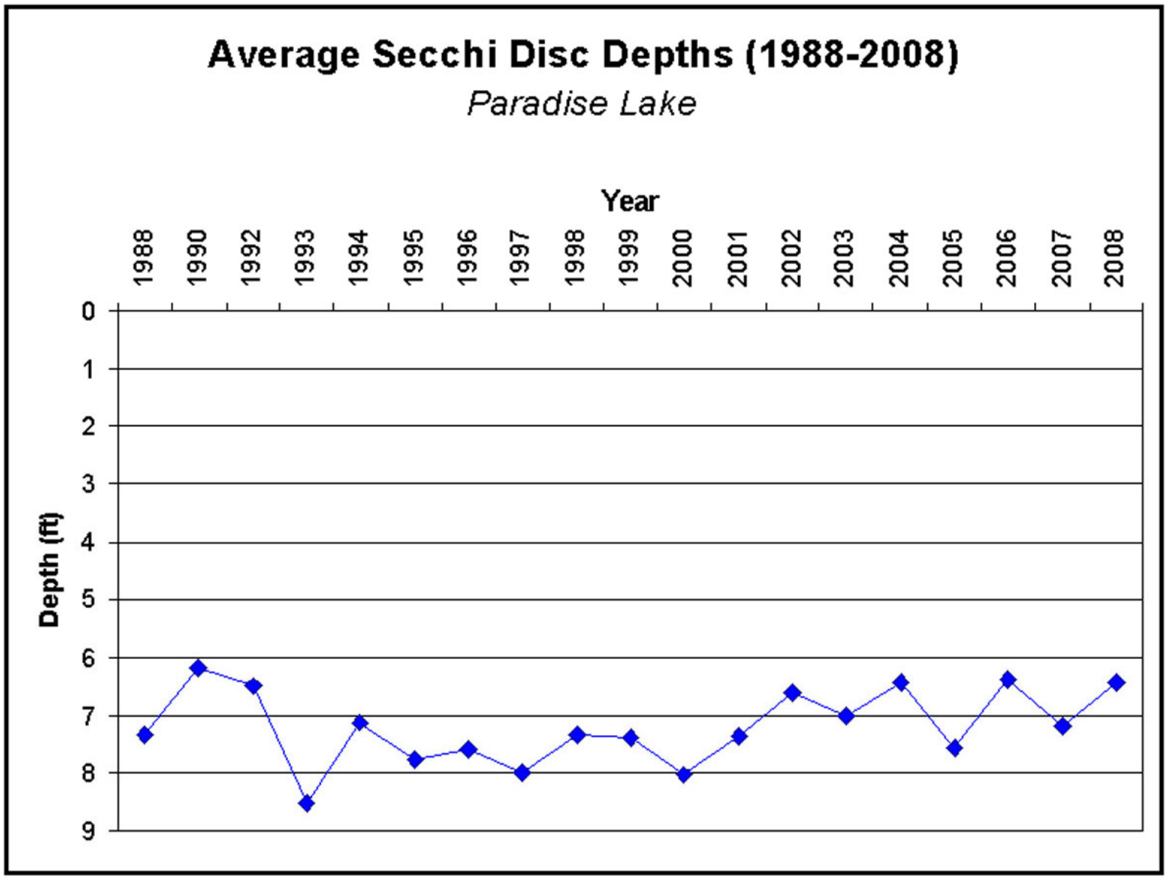
Summer, 1996, revised July, 1998

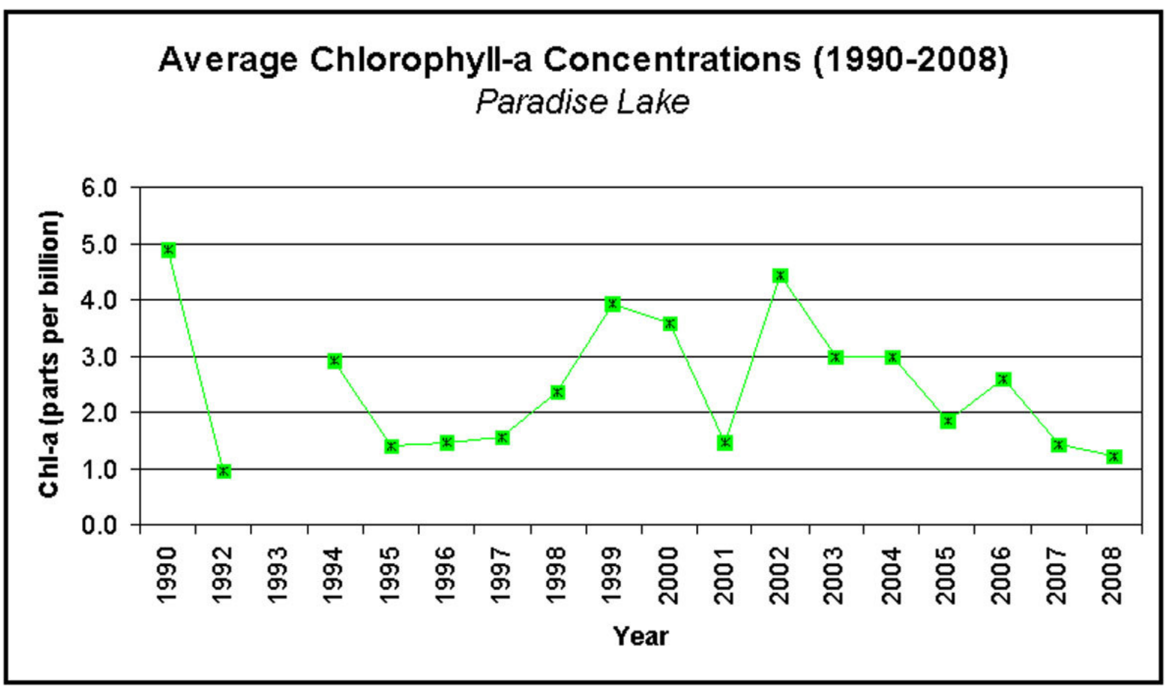


MAP LEGEND

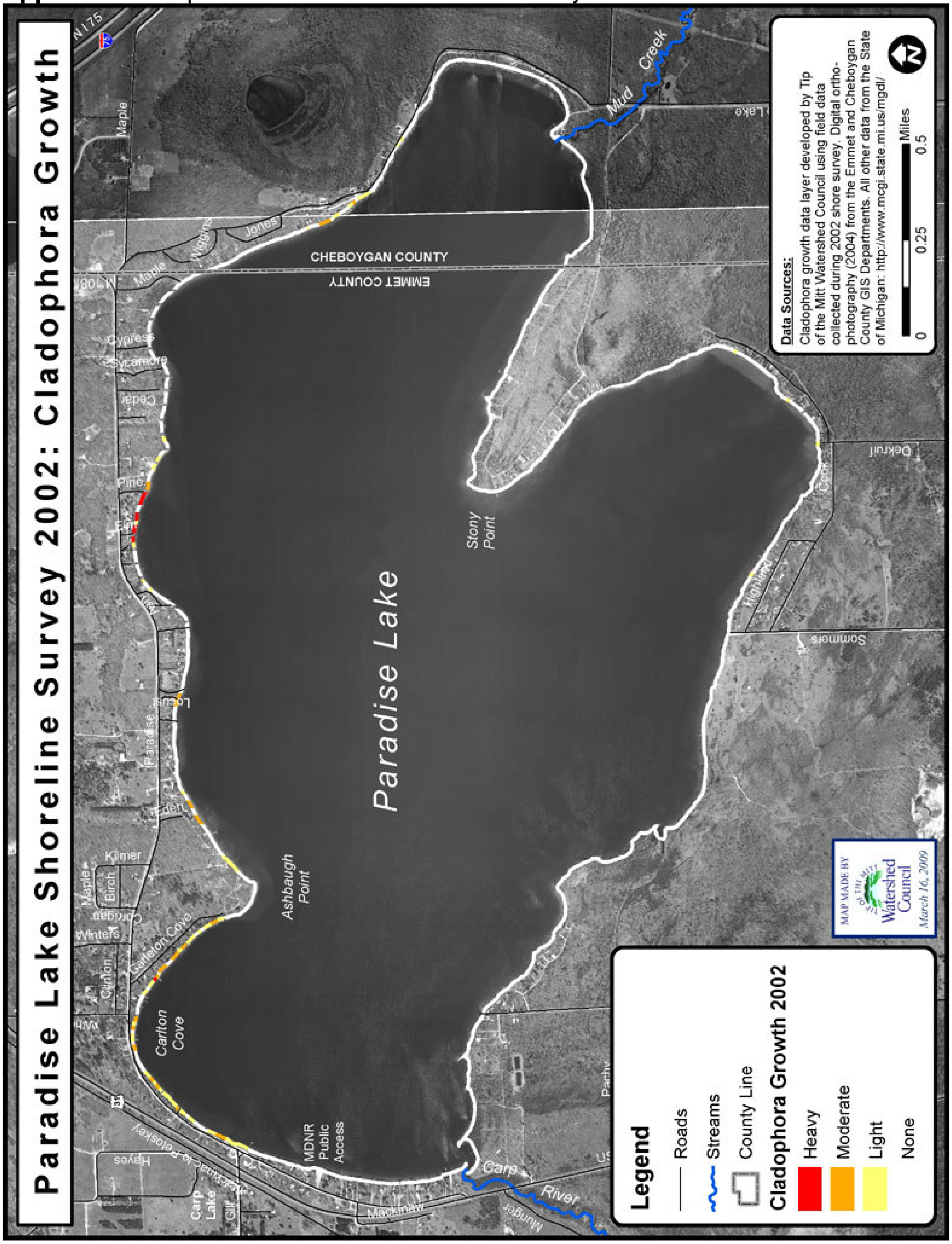
- = unvegetated areas generally shallower than 6 feet
- = diverse, low-growing vegetation community with relatively little Eurasian milfoil, generally 6-10 feet deep
- = dense vegetation beds reaching to the surface, dominated by Eurasian milfoil and whitestem pondweed, generally 6-10 feet deep
- = unvegetated areas generally deeper than 10 feet

Appendix B: Secchi depth and chlorophyll-a charts for Paradise Lake.





Appendix C: Map of Paradise Lake Shoreline Survey 2002 results.



Appendix D: Aquatic plant control options matrix.

AQUATIC PLANT CONTROL OPTIONS MATRIX		
**primary source: http://www.ecy.wa.gov/programs/wq/plants/management/*		
Control Method	**Advantages**	**Disadvantages**
Herbicide Application	Recreational activities such as swimming and boating improve.	Habitat and refuge loss for aquatic species that depend upon aquatic plants.
	Often get quick results, though some treatments take weeks or months.	Food source reduced or eliminated for aquatic organisms that feed on plants or on other organisms that live on/in plants.
	Short-term costs are generally low compared to other forms of treatment.	Native species may also be killed by the herbicide, weakening the native plant community and opening door to invasives.
	Herbicides and application services are readily available through a variety of companies.	Herbicides kill plants, but leaves decaying plant material in the water, which can lead to oxygen depletion and fish kills.
		Spot treatment using herbicide is prone to dispersal by winds, waves, and currents, potentially impacting non-target areas.
		Herbicides have been shown to migrate from surface waters into and contaminate groundwater.
		Some chemicals accumulate in sediments and may reach toxic levels for aquatic life occupying that niche.
		Full extent of chemical impacts on other organisms within the ecosystem are usually unknown.
		Resource expenditure (money and effort) is usually continual and long-term.
		Restricts use of some lake areas that must be closed for a time after herbicide application.
Manual plant removal	Able to remove plants from dock and swimming areas.	Treatment may need to be repeated several times each summer.
	Inexpensive.	Not practical for large areas or thick weed beds.
	Selective aquatic plant removal.	It is difficult to collect all plant fragments (most aquatic plants can re-grow from fragments).
	Environmentally sound.	Plants with large rhizomes, like water lilies, are difficult to remove.
		Loosened sediments have biological impacts in immediate area and makes it difficult to see remaining plants.
		Bottom-dwelling animals in affected area disturbed or killed.

Control Method	Advantages	Disadvantages
Cutters	Water area immediately opened, improving recreational opportunities.	Plants may need to be cut several times per season.
	May work in shallow waters not accessible to larger harvesters.	Some species are difficult to cut.
	Habitat for fish and other organisms is retained if the plants are not cut too short.	Plant fragments from cutting may enhance the spread of invasive plants such as Eurasian watermilfoil.
	Can target specific locations and protect designated conservancy areas.	Decomposing plant fragments potentially reduce dissolved oxygen in water (and create a nuisance when drifting to shore).
	Prices are much lower than harvesters.	Little or no reduction in plant density.
		Stirred sediments clog gills of fish and macroinvertebrates, smother small organisms and potentially reduce habitat when resettling.
Harvesting	Water area immediately opened, improving recreational opportunities.	Initial costs for equipment are high and maintenance is required.
	Removes plant nutrients, such as nitrogen and phosphorus, from the lake.	Plants may need to be cut several times per season.
	Harvesting as aquatic plants are dying back for the winter can remove organic material and help slow the sedimentation rate in a waterbody.	Little or no reduction in plant density (# of plants per area).
	Habitat for fish and other organisms is retained if the plants are not cut too short.	Must have off-loading sites and disposal areas for cut plants.
	Can target specific locations and protect designated conservancy areas.	Not easily maneuverable in shallow water or around docks or other obstructions.
		Small fish and other aquatic organisms are often collected and killed.
		Plant fragments from cutting may enhance the spread of invasive plants such as Eurasian watermilfoil.
		Decomposing plant fragments potentially reduce dissolved oxygen in water (and create a nuisance when drifting to shore).
		Stirred sediments clog gills of fish and macroinvertebrates, smother small organisms and potentially reduce habitat when resettling.
		May not be suitable for lakes with many bottom obstructions (stumps, logs).
		May not be suitable for very shallow lakes (3-5 feet of water) with loose organic sediments
		Harvesters from other waterbodies must be thoroughly cleaned and inspected to avoid introduction of exotic species.

Control Method	Advantages	Disadvantages
Dredging	Long-term control in areas that are sufficiently deepened.	Expensive.
	Water area immediately opened, improving recreational opportunities.	Sediments are stirred up, which could release nutrients or long-buried toxic materials into the water column.
	Plant material and nutrients or contaminants permanently removed from the lake.	Stirred sediments clog gills of fish and macroinvertebrates, smother small organisms and potentially reduce habitat when resettling.
	Diver dredging can selectively remove target species.	Bottom-dwelling animals in affected area disturbed or killed.
	Diver dredging can remove plants around docks and in other difficult to reach areas.	Aquatic plant root removal may destabilize lake bottom.
		Aquatic plant removal could lead to shoreline erosion as wave energy and currents are no longer absorbed.
		Root crowns may be missed and lead to future growth.
		Spoils must be properly disposed of.
Lake Drawdown	Cost effective, if water control structure is in place.	Costly if a water level control structure is not in place (requires high capacity pumps).
	Re-colonization by native aquatic plants in areas formerly occupied by exotic species can be enhanced.	Does not kill all plants and enhances growth of some aquatic plants.
	Game fish populations are reported to improve after drawdown.	Success in killing the target species dependent on weather (e.g. warm winters or wet summers).
	Provides an opportunity to repair and improve docks and other structures.	Docks and water intakes left high and dry, boat launching complicated, and well water levels may lower.
	Loose, flocculent sediments can become consolidated.	Exposing lake bottom areas impacts fish and other aquatic wildlife.
		Algal blooms have been reported to occur after drawdowns.

Control Method	Advantages	Disadvantages
Benthic Barriers	Water area immediately opened, improving recreational opportunities.	Only suitable for localized control, as barriers cover sediment and reduce habitat.
	Easy installation around docks and in swimming areas.	Require regular inspection and maintenance for safety and performance.
	Can control 100 percent of aquatic plants, if properly installed.	May be damaged or dislodged by anchors, harvesters, rotovators, fishing gear, propeller backwash, weather, etc.
	Materials for constructing barriers are often readily available.	Dislodged or improperly anchored barriers may create safety hazards for boaters and swimmers.
	Can be installed by homeowners or divers.	Swimmers may be injured by anchors used to fasten barriers.
		Some bottom screens are difficult to anchor on deep muck sediments.
		Barriers interfere with fish spawning and bottom-dwelling animals.
		Aquatic plants may quickly recolonize if barrier is not maintained.
		Not effective against free-floating plants.
Biological control	Long-term solution, if successful.	Usually only effective against one target species.
	Long-term maintenance is minimal.	May introduce a non-native species.
	No chemicals introduced, sediments are not disturbed, other aquatic organisms not sacrificed.	Bio-control agents may not be available for plant in question or not commercially available.
		Slow process, taking years.
		Success is not guaranteed.
		Initial stocking and survey costs are usually high.

Appendix E: Herbicides approved by Michigan DEQ and target species.

DEQ
MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER BUREAU

This table contains information concerning the herbicides permitted for aquatic plant and algae control in Michigan and the plant species for which they may serve as potential control agents. Refer to product labels for additional details.

Permits may be required prior to use of any pesticide, including "unclassified" pesticides. Contact the DEQ, Aquatic Nuisance Control & Remedial Action Unit at 517-241-7734, by e-mail at DEQ-LWM-ANC@michigan.gov, or visit our website at www.michigan.gov/deq.

Common Plant Species	Copper Sulfate	Chelated Copper	Amine Salts of Endothall* (Hydrothol 191)	Dipotassium Salts of Endothall* (Aquathol K)	Diquat dibromide** (Reward)	2,4-D* (Navigate, Aquakleen, Aquacide)
Algae						
Filamentous	x	x	x		x	
Macroalgae (e.g., Chara)	x	x	x			
Planktonic	x	x	x			
Macrophytes						
Submergents						
Coontail			x	x	x	x
Curly leaf pondweed			x	x	x	
Elodea			x		x	
Large leaf pondweed			x	x	x	
Milfoil			x	x	x	x
Naiad			x	x	x	
Sago pondweed			x	x	x	
Wild Celery			x		x	
Emergents						
Arrowhead						x
Bulrush						x
Cattails						x
Phragmites						
Purple Loosestrife						
Water lily						x
Free Floating						
Duckweed					x	

* Granular endothall and/or granular 2,4-D products may not be applied within 75 feet of ANY drinking water well or within 250 feet of drinking water wells that are less than 30 feet deep. Isolation distances are measured from the well location, not the shoreline.

** Diquat products are restricted for all aquatic uses, except in small ponds, such as farm ponds that have no outflow and are under the control of the user. This means that you must be licensed by the Michigan Department of Agriculture as a certified pest control applicator to use this material in all waterbodies except small ponds. Diquat is the only "Restricted Use" pesticide on the chart. All others are "Unclassified."

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER BUREAU

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Common Plant Species	Fluridone (Sonar, AVAST!)	Glyphosate (Rodeo, Eagre, AquaNeat)	Imazapyr**** (Habitat)	Komeen	Nautique	Sodium Carbonate Peroxyhydrate (GreenClean Pro, Pak 27*****)	Triclopyr (Renovate 3)
Algae							
Filamentous						x	
Macroalgae (e.g., Chara)							
Planktonic						x	
Macrophytes							
Submergents							
Coontail				x			
Curly leaf pondweed							
Elodea				x			
Large leaf pondweed							
Milfoil	x***			x			x
Naiad				x	x		
Sago pondweed				x			
Wild Celery					x		
Emergents							
Arrowhead							
Bulrush			x				
Cattails		x	x				
Phragmites							
Purple Loosestrife		x	x				x
Water lily	x	x					x
Free Floating							
Duckweed			x				

*** Fluridone use may require a Lake Management Plan. Rates requested above 6 ppb must follow evaluation protocol.

**** As indicated on the label, application of Habitat can only be made by applicators who are licensed or certified as aquatic pest control applicators and are authorized by the state or local government.

***** The label indicates use for treatment of blue-green algae.