# Aquatic Vegetation Survey 2008
# for Crooked and Pickerel Lakes

*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. Heavy aquatic plant growth can occur naturally given the correct combination of environmental variables (e.g., light and nutrient availability), but is accelerated due to factors such as nutrient pollution or the introduction of non-native species.

Concerns regarding non-native (invasive) species and fisheries habitat in Crooked and Pickerel Lakes (Emmet County, Michigan) prompted the Pickerel-Crooked Lakes Association to sponsor a comprehensive aquatic plant survey. During the summer of 2008, Tip of the Mitt Watershed Council staff collected specimens and documented plant densities at 479 sites throughout Crooked and Pickerel Lakes. A total of 31 aquatic plant taxa were documented during the survey. Slender naiad (*Najas flexilis*), muskgrass (*Chara spp.*), slender naiad (*Najas flexilis*), variable-leaf watermilfoil (*Myriophyllum heterophyllum*), and eel-grass (*Valisneria americana*) were the most commonly collected species and dominant at the greatest number of sample sites. Only one invasive species, curly-leaf pondweed (*Potamogeton crispus*) was found during this survey and at only one site.

Aquatic plant communities were delineated directly in the field using a GPS (global positioning system) or indirectly through interpolation or extrapolation of sample site data. Plant community data showed that a majority of Crooked and Pickerel Lakes (54%) contained no or little aquatic vegetation. Reflecting sample site results, muskgrass, slender naiad and eel-grass commonly dominated the lake's aquatic plant communities. However, bulrush (*Schoenoplectus spp.*) dominated the largest portion of aquatic plant communities in terms of areal extent.

The aquatic plant communities of Crooked and Pickerel Lakes predominantly contained light to moderate density growth (76% of the vegetated area). Relatively little heavy-density growth was documented and very heavy growth was found only in Crooked Lake and limited to 17 acres. A few areas in Crooked Lake and no areas in Pickerel Lake contained what is generally considered to be nuisance plant growth. Areas of dense vegetation in Crooked Lake (classified as very heavy) were limited to the southwest corner and in two locations along the northern shore. Nutrient inputs

from residential and commercial development of shoreline areas probably contribute to the heavy growth found in these areas. Furthermore, Round Creek, which flows into the southwest corner of Crooked Lake, likely contributes to the heavy plant growth in that area as streams typically contain higher levels of nutrients than lakes in this region.

Invasive species and nutrient pollution may be contributing to aquatic plant growth throughout Crooked and Pickerel Lakes. Invasive zebra mussels (*Dreissena polymorpha*) are present in both lakes and potentially increase plant growth by altering the lake ecosystem. Human development of the landscape and activity in nearshore areas invariably leads to unnaturally elevated nutrient inputs into the lake, which contribute to aquatic plant growth.

The Pickerel-Crooked Lakes Association should share results from this survey to maximize benefits and assist in lake management efforts. Shoreline areas should be surveyed for evidence of nutrient pollution and any problem areas addressed to prevent or reduce nuisance aquatic plant growth. The Lake Association should continue manual removal efforts to control the curly-leaf pondweed infestation. Manual removal is recommended because it is adequate for controlling small infestations and has minimal impacts on the lake ecosystem. Additionally, the Association should regularly survey other lake areas for the presence of curly-leaf pondweed and implement control measures as necessary.

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. Future surveys are recommended to collect the necessary 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.

# 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 probably experience declining fisheries due to habitat and food source losses. Aquatic plant loss may also result in decreased 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 growth, 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 step in developing a sound lake management program is to survey the aquatic plant communities to document species, abundance, density, and the presence of non-native species. In 2008, the Pickerel-Crooked Lakes Association contracted with Tip of the Mitt Watershed Council to perform a comprehensive aquatic plant survey of

Crooked and Pickerel Lakes. Survey field methods, data management procedures, project results, and discussion of results are contained in this report.

**Study area:**

Crooked and Pickerel Lakes are located in southeast Emmet County in the northern tip of the Lower Peninsula of Michigan. The lakes are split between Springvale and Littlefield Townships, with the western edge of Crooked Lake touching upon Little Traverse and Bear Creek Townships. Oden Island, in the middle of Crooked Lake, effectively splits the lake into two basins to the east and west of the island, though the far western area of the lake (to the west of Graham Point) could be considered a third distinct basin. Pickerel Lake, located to the east of Crooked Lake and connected by a half-mile channel, is composed of two basins to the northwest and southeast of a narrow area located in front of Ellsworth Point.

Based upon digitization of aerial orthophotography (2004) acquired from the Emmet County GIS (Geographical Information System) Department, the Crooked Lake shoreline measures 16.3 miles and the lake surface area totals 2,351 acres whereas Pickerel Lake has 7.1 miles of shoreline and 1082.5 acres of surface area. The connecting channel between the lakes accounts for an additional 1.3 miles of shoreline and 13.3 acres of surface area. Crooked Lake measures approximately 3.5 miles from west to east at its widest point and 1.75 miles from north to south. From northwest to southeast, Pickerel Lake measures roughly 2.5 miles and has a maximum width of less than a mile.

Crooked and Pickerel Lakes contain extensive shallow areas, but there are deep pockets in both lakes as well. Maps from the Michigan Department of Natural Resources (MDNR) Institute for Fisheries Research indicate that the deepest point in Crooked Lake, 50 feet, is located to the west of Oden Island. There are two deep holes in Pickerel Lake that approach 70 feet of depth and which are located in the northwest basin. The broad near-shore shallow areas of both lakes support large communities of emergent vegetation.

Crooked and Pickerel Lakes are drainage lakes of glacial origin. The largest inlet streams on Crooked Lake include Round Creek on the west end, Oden Creek on the north shore, Minnehaha Creek near the southern tip and the Black Hole channel connecting to Pickerel Lake on the east end. Inlet streams to Pickerel Lake include Cedar Creek on the east end, Mud Creek on the west side and an unnamed creek on the east end of the north shore. Water leaves Pickerel Lake through the Black Hole channel and flows out of Crooked Lake in the northeast corner into the Crooked River.

Following the retreat of glaciers (~14,000 years ago) that covered the region during the last ice age, water flowed west across the state, through the Crooked-Pickerel Lakes' area and out to Little Traverse Bay. During the Lake Nipissing stage, some 4,000 years ago, dunes rose up to the west of Round Lake and cut off stream flow into Little Traverse Bay (Spur and Zumberge, 1956). The dune formation effectively reversed the course of the streams and rivers, gradually forming the current Inland Waterway flow path across the State to the east-northeast, discharging into Lake Huron at the City of Cheboygan.

The Crooked and Pickerel Lakes watershed, according to GIS files developed by the Watershed Council using existing watershed boundary and elevation data acquired from the State of Michigan, encompasses 75,557 acres, which includes the lake area (Figure 1). The watershed size without the lake area totals 72,110 acres, giving a watershed area to lake area ratio of 20.92. The ratio provides a statistic for assessing impacts from agricultural, urban, and other development in the watershed. Crooked and Pickerel Lakes collectively have over 20 acres of land in the watershed for each acre of the lakes' surface area, which is a considerable buffer for moderating water quality impacts from landscape development and human activity in the watershed.

Land cover statistics for the Crooked and Pickerel Lakes watershed were generated using remotely sensed data from the Coastal Great Lakes Land Cover project (Table 1). Based on the 2006 data, there is little agricultural landcover within the watershed (~9.8%) and even less urban (~3.3%). The majority of the watershed's landcover is natural, consisting of forest, grasslands, and wetlands. During the five-year period between 2001 and 2006, both agricultural and urban land-cover area increased. However, the increase during this period for both of these landcover types was less than 1%.

**Figure 1.** Map of the Crooked and Pickerel Lakes Watershed.

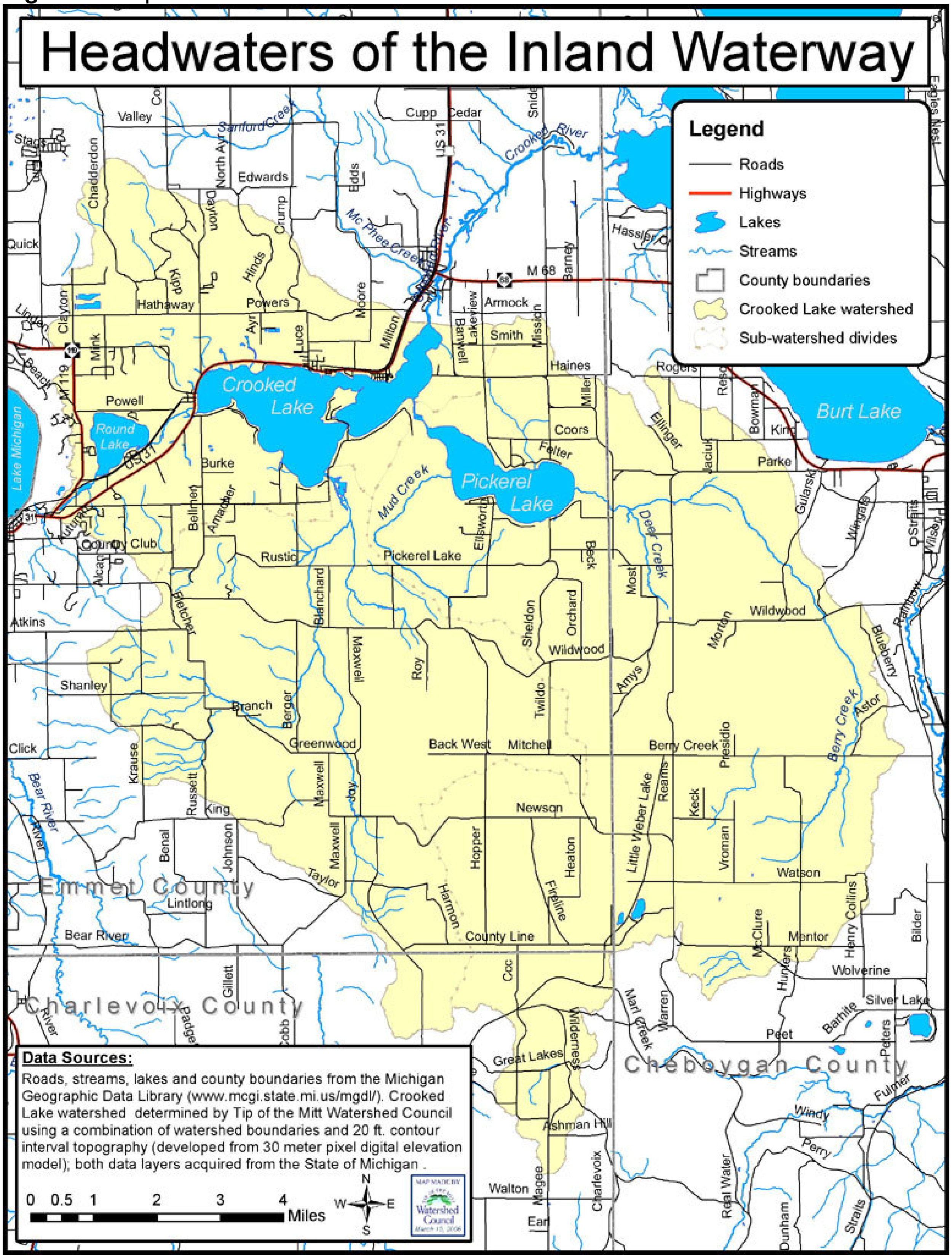


**Table 1.** Crooked and Pickerel Lakes watershed land-cover statistics.

| Land Cover Type | Acres (2001) | Percent (2001) | Acres (2006) | Percent (2006) | Percent Change (2001-2006) |
|---|---|---|---|---|---|
| Agriculture | 6891.24 | 9.12 | 7369.45 | 9.75 | 0.63 |
| Barren | 313.91 | 0.42 | 270.49 | 0.36 | -0.06 |
| Forested | 42848.18 | 56.70 | 44139.80 | 58.38 | 1.68 |
| Grassland | 9685.70 | 12.82 | 6010.48 | 7.95 | -4.87 |
| Scrub/shrub | 2193.04 | 2.90 | 2862.49 | 3.79 | 0.88 |
| Urban | 1869.81 | 2.47 | 2482.86 | 3.28 | 0.81 |
| Water | 3997.20 | 5.29 | 3970.57 | 5.25 | -0.04 |
| Wetlands | 7770.27 | 10.28 | 8496.16 | 11.24 | 0.96 |
| TOTAL | 75569.34 | 100.00 | 75602.31 | 100.00 | NA |

The water quality of Crooked and Pickerel Lakes has been monitored for many years. The Pickerel-Crooked Lakes Association has actively supported water quality monitoring programs on Crooked and Pickerel Lakes, providing volunteers for the Volunteer Lake Monitoring program (VLM) coordinated by the Tip of the Mitt Watershed Council. In addition, Crooked and Pickerel Lakes is monitored by Watershed Council staff as part of the Comprehensive Water Quality Monitoring program (CWQM).

Volunteer Lake Monitoring program data show that averaged Secchi disc depths on Crooked Lake have ranged from 7 to 14 feet while ranging from 7 to 11 feet on Pickerel Lake (Figure 2). There seems to be a trend of increasing clarity over time, particularly in Pickerel Lake. Water clarity is usually determined by two key factors: sediments and phytoplanktonic algae. Little sediment in the water is desirable, but too little algae can impact the lake ecosystem. A decrease in phytoplanktonic algae equates to a loss in primary productivity, which has cascading effects throughout the food chain. Invasive zebra mussels (*Dreissena polymorpha*), observed in Crooked and Pickerel Lakes during the survey, filter-feed on phytoplanktonic algae, which typically results in greater water clarity. However, chlorophyll-a measurements, which provide an indication of algal biomass in the lakes, have not decreased as typically occurs when zebra mussels become established in a lake (Figure 3). Lack of clear trends and irregularities in the data may be the result of inconsistent data collection or simply due to natural variability.

Based on trophic status index data from the VLM program, both Crooked and Pickerel Lakes border between mesotrophy and oligotrophy (Figure 4). Oligotrophic

**Figure 2.** Chart of Secchi disc depth data from Crooked and Pickerel Lakes.

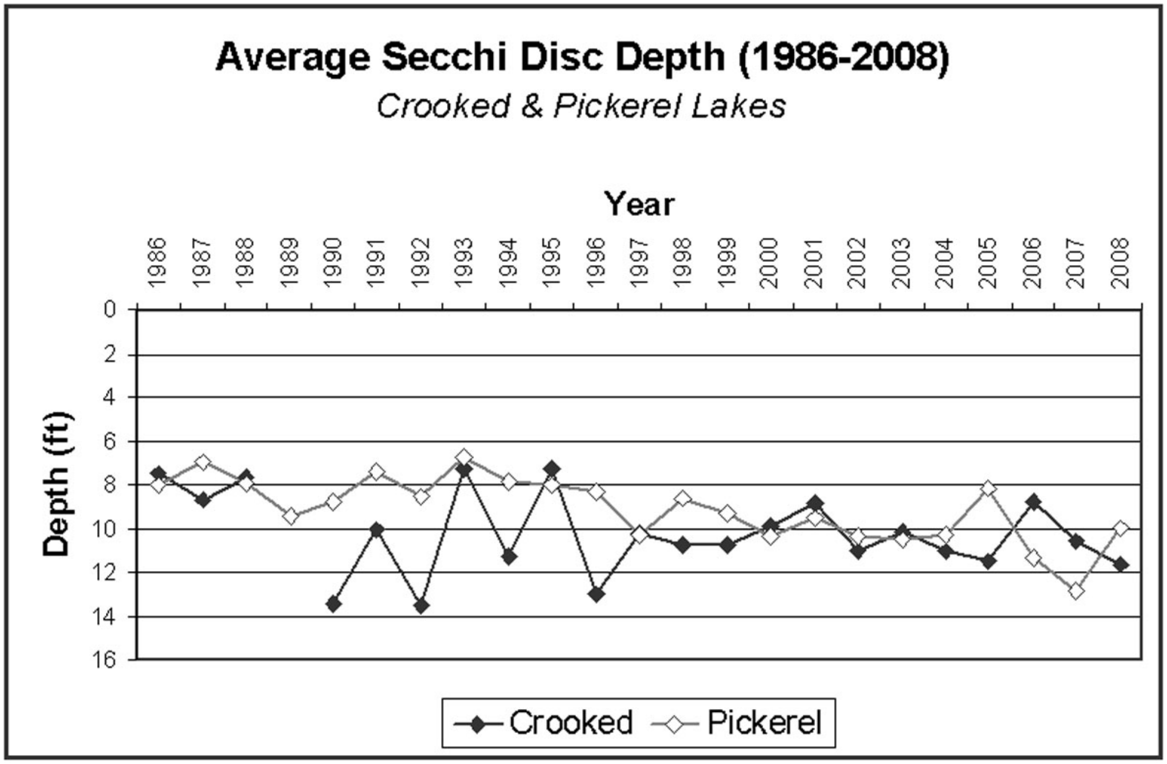



**Figure 3.** Chart of chlorophyll-a data from Crooked and Pickerel Lakes.

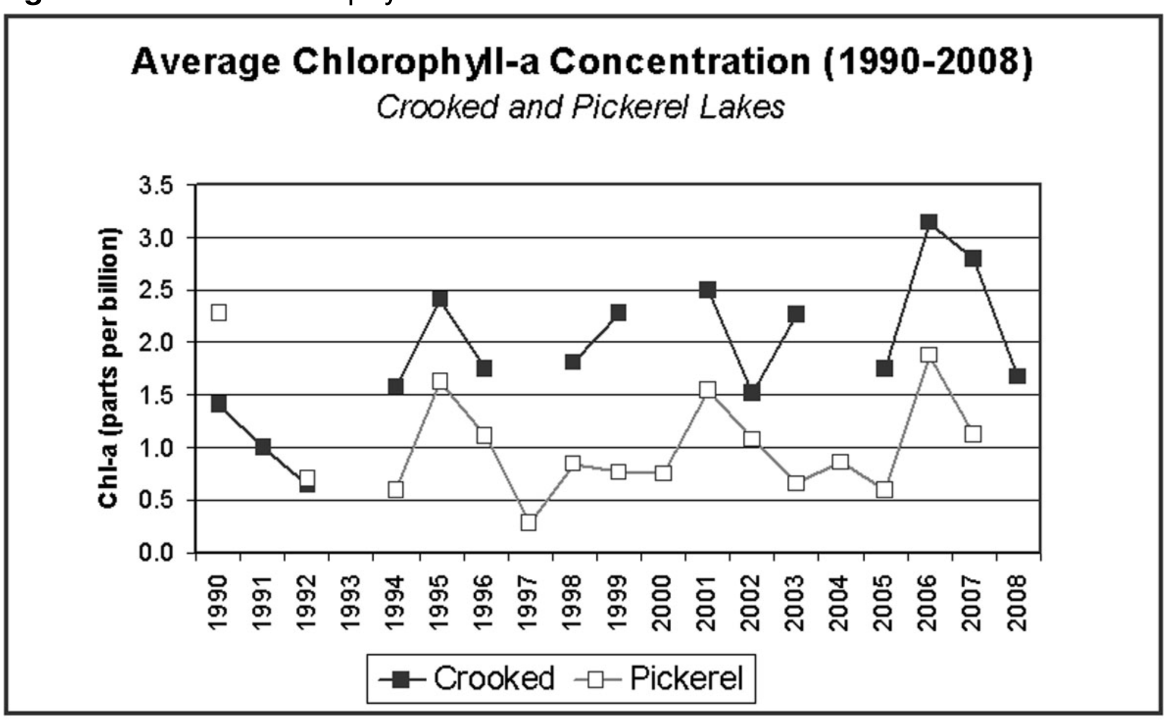
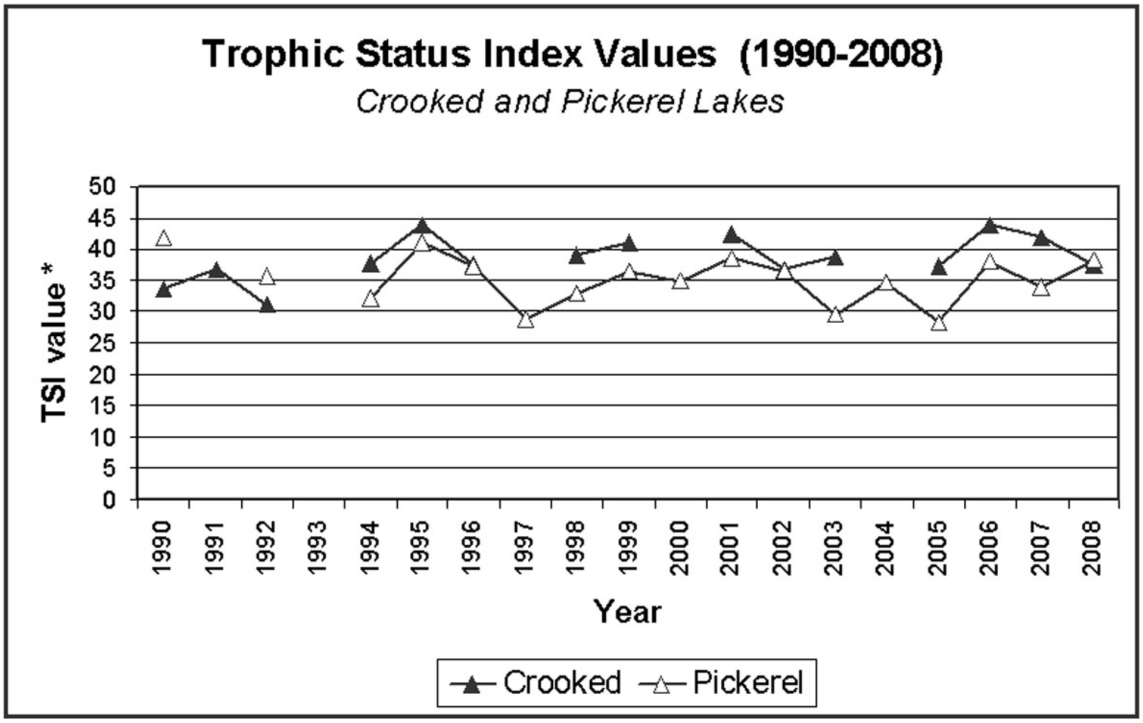


**Figure 4.** Chart of trophic status index data from Crooked and Pickerel Lakes.

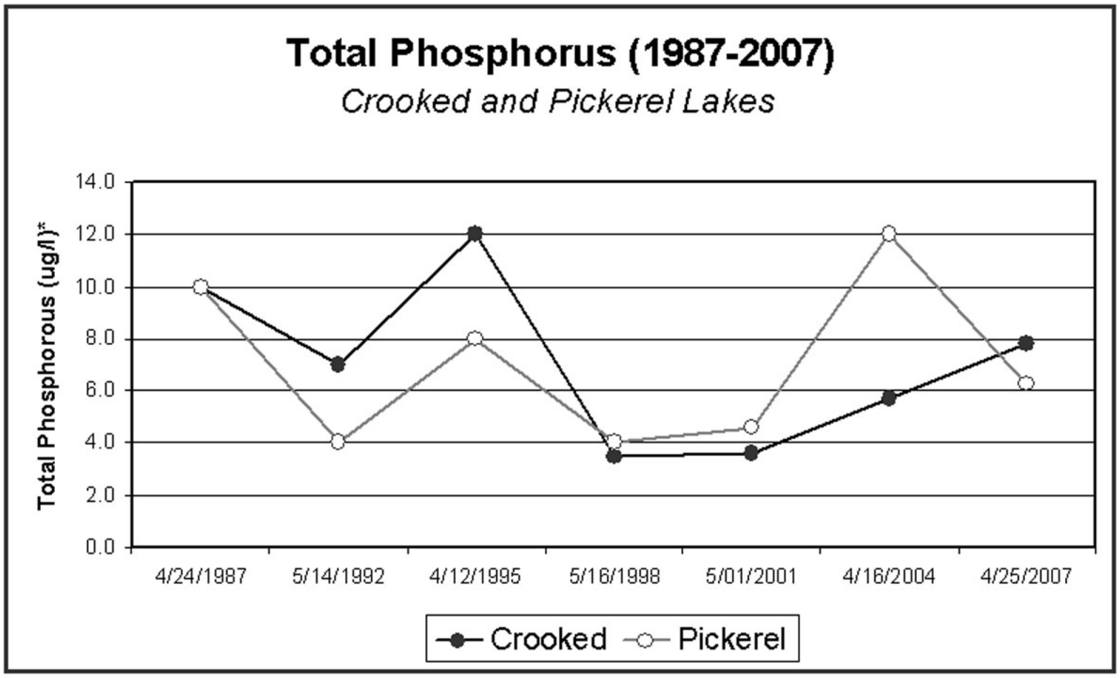



**TSI values indicate the trophic status of lake: 0-38 = oligotrophic (low productive system), 39-49 = mesotrophic (moderately productive system), and 50+ = eutrophic (highly productive system).*

lakes are typically large, deep, clear, and nutrient poor. In general, oligotrophic lakes contain high quality waters, but paradoxically have a lackluster fisheries due to low biological productivity. Mesotrophic lakes are moderately productive. Phosphorus data collected in the CWQM program has also varied throughout time, showing no clear trends (Figure 5). Phosphorus concentrations of 10 parts per billion (PPB) or less are characteristic for oligotrophic lakes of northern Michigan.

Surveys by MDNR show that Crooked and Pickerel Lakes support a mix of fish species typical for lakes of Northern Michigan. Fish species collected during a 2001 survey include alewife, black bullhead, black crappie, bluegill, bowfin, brown bullhead, brown trout, burbot, common carp, largemouth bass, longnose gar, northern pike, pumpkinseed, rainbow trout, rock bass, smallmouth bass, walleyes, white sucker, yellow bullhead, and yellow perch (Hanchin et. al., 2005). Additional forage fish collected with seine nets in a 1954 survey include a number of shiners, darters, and other species. Walleye and pike populations are generally characterized as having slow growth rates, which may be the result of inadequate forage.

**Figure 5**. Chart of phosphorus data from Crooked and Pickerel Lakes.




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

# METHODS

Field data for the Crooked and Pickerel Lakes aquatic plant survey were collected in August and early September of 2008. Aquatic plants were documented in all lake areas and in the channel connecting the two lakes. Consistent with Michigan Department of Environmental Quality procedures, the aquatic plant communities of Crooked and Pickerel Lakes were surveyed using rake tows and through visual observations (MDEQ, 2001). After completing the field survey, data collected in the field were processed and used to produce maps displaying the lake's aquatic plant communities.

**Documenting aquatic plants at sample sites:**

Specimens were collected, identified, photographed and recorded in a notebook at 479 sample sites throughout the lakes to document aquatic plant taxa (335 sites on Crooked Lake, 135 sites on Pickerel Lake, and 9 sites in the channel). Sample site locations were not random, but rather selected with the intent of collecting representative information on all aquatic plant communities currently inhabiting the lake. Most sampling was conducted along transects across the lake that were spaced at regular intervals. In expansive, deep areas, transects began near the shoreline and continued straight out toward deeper waters until plants were no longer found. The distance between sample points along transects varied depending upon plant community changes that were visible from the surface. In areas where plant communities were not visible, sample sites were selected based on interpretation of signals from the depth-finder or at regular intervals along the transect.

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. The location of each sampling station was recorded using a Trimble GeoExplorer3 GPS unit with a reported accuracy of 1-3 meters.

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). In general, the category "very heavy" was assigned when plant growth was so heavy that it reached the surface and formed a continuous mat. At the other end of the spectrum, "very light" indicated sparse vegetation where only a few stems or pieces were found. Overall plant density for the site was 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 Crooked and Pickerel Lakes, 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:**

Plant communities can be delineated simply by interpolating or extrapolating between sample points, but the accuracy of such delineations can be greatly improved by noting and mapping precise locations where one plant community type ends and another begins. Therefore, additional data were collected to improve the accuracy of delineations between distinct plant communities in the lake. 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. The depth finder was also used to delineate plant communities as signals show transitions between vegetated and non-vegetated areas. Plant specimens were not collected while mapping community lines with GPS.

Emergent plant beds were mapped by volunteers from the Pickerel-Crooked Lake Association. Volunteers were trained by Watershed Council staff in emergent plant species identification and GPS data collection using the Trimble GeoExplorer3. Emergent plants growing directly along the shoreline were frequently mapped at an offset distance that was recorded in the GPS unit.

In spite of sampling at 479 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. Additionally, emergent plant bed mapping may contain errors resulting from misinterpretation of GPS data and associated comments collected by volunteers.

**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 during plant community mapping. All GIS work was performed using ESRI GIS software: 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 4.0. 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. 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 = "Crooked-Pickerel_APsurvey2008_001-0_tag.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.

Delineations of aquatic plant communities recorded with GPS were used to develop polygons representing community types occurring in the lake. If borders between plant communities were not mapped directly with GPS in the field, then divisions between plant communities were determined by interpolating between or extrapolating from sample site points. Field notes from sample sites were also consulted during delineation of plant communities. After developing polygons, area statistics for specific plant communities and associated densities 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 densities at sample sites, dominant plant communities, and plant community densities. 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 31 aquatic plant taxa were documented during the survey conducted on Crooked and Pickerel Lakes, including three emergent taxa noted in comments or mapped with GPS, but not listed in the database (cattail, sweet gale, and three-square bulrush). Of the 479 locations sampled, aquatic plants were found at 350 sites (73%) while 129 sites (27%) had little or no vegetation. The number of aquatic plant taxa encountered at a site ranged from zero to 10 with an average of 2.4 taxa per sample site. Only one invasive plant species was encountered during this survey: curly-leaf pondweed.

Slender naiad, muskgrass, variable-leaf watermilfoil, and eel-grass were the most commonly encountered species; collected at approximately 58%, 58%, 49%, and 47% of sites respectively (Table 2). Six other taxa were collected at 25 sites or more and considered common; including bulrush, broad-leaf pondweed, common bladderwort, elodea, flat-stem pondweed, and variable-leaf pondweed. Eleven plant taxa occurred uncommonly, which was defined as occurring at 6 to 24 sites and the remaining seven taxa were rarely collected (occurring at 5 sites or less).

The plants most commonly collected were also those that dominated or co-dominated plant communities at the greatest number of sample sites. However, whereas slender naiad and muskgrass were collected at approximately the same number of sites, muskgrass was by far the most dominant, dominating plant communities at 140 sites (Table 3). Slender naiad and eel-grass were nearly equal in terms of dominance, dominating at 104 and 99 sites respectively, and variable-leaf watermilfoil followed with 70 sites. Bulrush also commonly dominated plant communities, doing so at 54 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 12 pondweed species were documented in Crooked and Pickerel Lakes during this survey. However, pondweeds were generally not observed growing at heavy densities and did not commonly dominate aquatic plant communities.

**Figure 6.** Map of sample sites on Crooked and Pickerel Lakes.

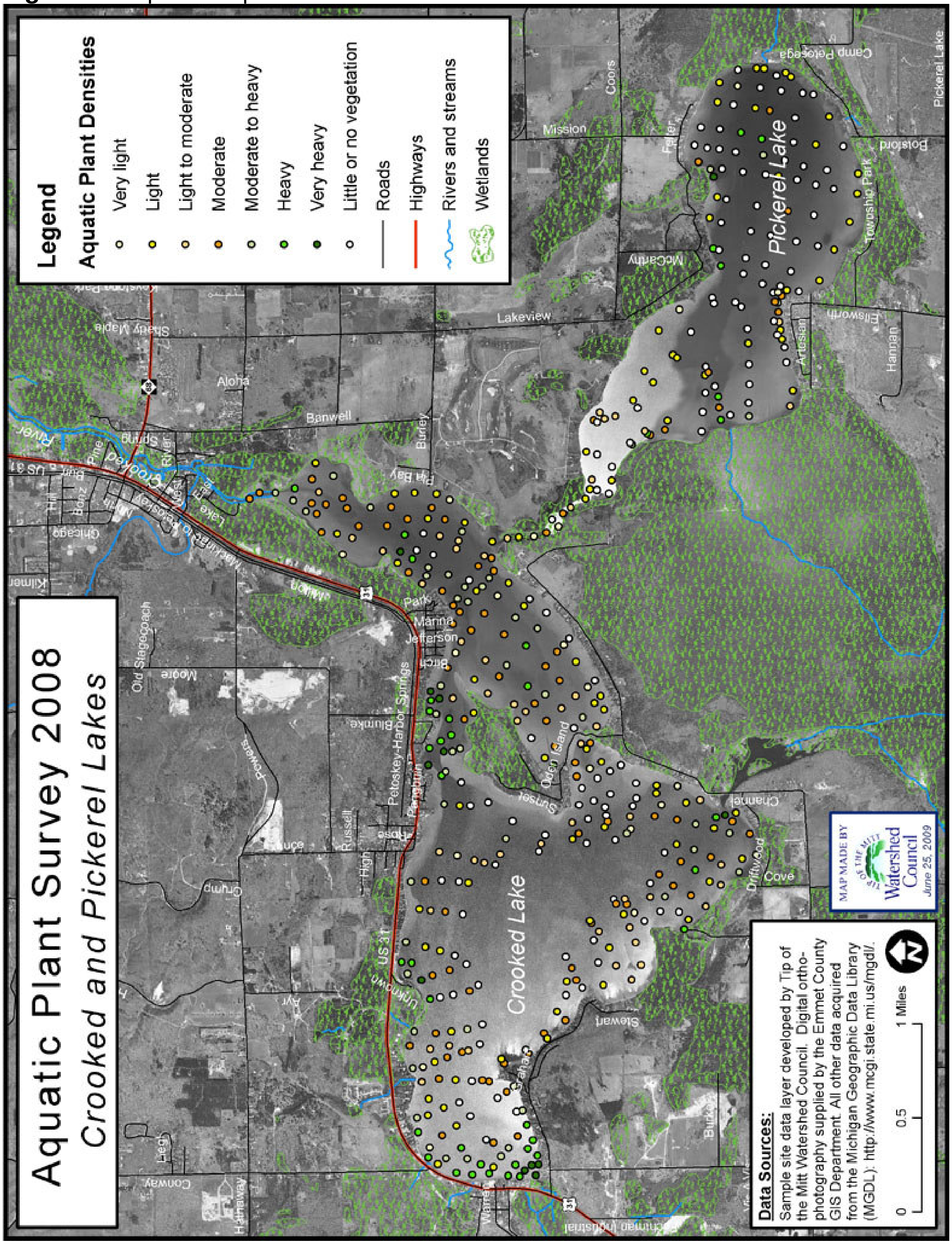


**Table 2.** Aquatic plant taxa occurrence at sample sites.

| Genus and species | Common Name | Number of sites | Percent of sites* | Occurrence† |
|---|---|---|---|---|
| *Najas flexilis* | Slender naiad | 203 | 58.0 | Bountiful |
| *Chara spp.* | Muskgrass | 202 | 57.7 | Bountiful |
| *Myriophyllum heterophyllum* | Variable-leaf watermilfoil | 173 | 49.4 | Bountiful |
| *Vallisneria americana* | Eel-grass | 164 | 46.9 | Bountiful |
| *Potamogeton amplifolius* | Broad-leaved pondweed | 70 | 20.0 | Common |
| *Potamogeton zosteriformis* | Flat-stem pondweed | 60 | 17.1 | Common |
| *Schoenoplectus spp.* | Hard/soft-stem bulrush | 58 | 16.6 | Common |
| *Utricularia vulgaris* | Common bladderwort | 40 | 11.4 | Common |
| *Potamogeton gramineus* | Variable-leaf pondweed | 35 | 10.0 | Common |
| *Elodea canadensis* | Elodea | 27 | 7.7 | Common |
| *Potamogeton natans* | Floating-leaf pondweed | 21 | 6.0 | Uncommon |
| *Stuckenia pectinata* | Sago pondweed | 19 | 5.4 | Uncommon |
| *Potamogeton praelongus* | Whitestem pondweed | 14 | 4.0 | Uncommon |
| *Sagittaria spp.* | Arrowhead | 13 | 3.7 | Uncommon |
| *Potamogeton strictifolius* | Narrow-leaf pondweed | 11 | 3.1 | Uncommon |
| *Potamogeton richardsonii* | Richardson’s pondweed | 8 | 2.3 | Uncommon |
| *Schoenoplectus subterminalis* | Swaying bulrush | 8 | 2.3 | Uncommon |
| *Potamogeton illinoensis* | Illinois pondweed | 7 | 2.0 | Uncommon |
| *Sparganium angustifolium* | Narrow-leaf bur-reed | 7 | 2.0 | Uncommon |
| *Megalodonta beckii* | Water marigold | 6 | 1.7 | Uncommon |
| *Potamogeton robbinsii* | Robbins' pondweed | 6 | 1.7 | Uncommon |
| *Nuphar variegata* | Yellow pond-lily | 5 | 1.4 | Rare |
| *Nymphaea odorata* | White pond-lily | 3 | 0.9 | Rare |
| *Potamogeton friesii* | Fries' pondweed | 2 | 0.6 | Rare |
| *Ceratophyllum demersum* | Coontail | 1 | 0.3 | Rare |
| *Heteranthera dubia* | Water stargrass | 1 | 0.3 | Rare |
| *Potamogeton crispus* | Curly-leaved pondweed | 1 | 0.3 | Rare |
| *Potamogeton pusillus* | Fine-leaved pondweed | 1 | 0.3 | Rare |

**Percent of sites based on only those sites with vegetation (=350).*

*†Occurrence categories determined by Watershed Council staff based on natural breaks: 1-5 = rare, 6-24 = uncommon, 25-100 = common, and 100+ = bountiful.*

**Table 3.** Aquatic plant taxa dominance at sample sites

| Aquatic Plant Species | Common Name | Number of sites where dominant* | Percent of sites where dominant* |
|---|---|---|---|
| *Chara spp.* | Muskgrass | 141 | 40.3 |
| *Najas flexilis* | Slender naiad | 104 | 29.7 |
| *Vallisneria americana* | Eel-grass | 99 | 28.3 |
| *Myriophyllum heterophyllum* | Variable-leaf watermilfoil | 70 | 20.0 |
| *Schoenoplectus spp.* | Hard/soft-stem bulrush | 54 | 15.4 |
| *Potamogeton amplifolius* | Broad-leaf pondweed | 28 | 8.0 |
| *Potamogeton zosteriformis* | Flatstem pondweed | 15 | 4.3 |
| *Potamogeton gramineus* | Variable-leaf pondweed | 14 | 4.0 |
| *Utricularia vulgaris* | Common bladderwort | 14 | 4.0 |
| *Stuckenia pectinata* | Sago pondweed | 6 | 1.7 |
| *Potamogeton natans* | Floating-leaf pondweed | 5 | 1.4 |
| *Schoenoplectus subterminalis* | Swaying bulrush | 5 | 1.4 |
| *Potamogeton strictifolius* | Narrow-leaf pondweed | 4 | 1.1 |
| *Sparganium spp.* | Bur-reed | 4 | 1.1 |
| *Potamogeton illinoensis* | Illinois pondweed | 3 | 0.9 |
| *Sagittaria spp.* | Arrowhead | 3 | 0.9 |
| *Nuphar variegata* | Yellow pond-lily | 2 | 0.6 |
| *Elodea canadensis* | Elodea | 1 | 0.3 |
| *Megalodonta beckii* | Water marigold | 1 | 0.3 |
| *Potamogeton pusillus* | Fine-leaf pondweed | 1 | 0.3 |
| *Potamogeton richardsonii* | Richardson's pondweed | 1 | 0.3 |
| *Potamogeton robbinsii* | Robbins' pondweed | 1 | 0.3 |

**Number or percent of sites where taxon was dominant or co-dominant.*

Overall, the distribution in aquatic plant community densities at sample sites leaned toward light-density growth (Table 4). Approximately 33% of sample sites had aquatic plant community densities that fell into the light categories (VL, L, and LM). Moderate growth was documented at over 18% of sites and heavy-density growth (MH, H, and VH) accounted for 22%. The remaining sites had little or no vegetation (27%). Over 82% of sample sites on Crooked Lake had vegetation with nearly 27% of sites in the MH, H, or VH categories. Conversely, over 50% of sample sites on Pickerel Lake had little or no vegetation and less than 10% of sites had plant densities in the MH, H, or VH categories. Clusters of heavy-density growth were found only in Crooked Lake; primarily in the west end and between Oden Island and the north shore.

Curly-leaf pondweed (*Potamogeton crispus*) was the only invasive species found in the submerged aquatic plant communities of Crooked and Pickerel Lakes. Curly-leaf pondweed was found at only one site (site #417), located at the mouth of Oden (or Hatchery) Creek on the north side of Crooked Lake. The density of the infestation was noted as light to moderate.

**Table 4.** Aquatic plant densities at sample sites.

| Density Category | Both Lakes (# of sites) | Both Lakes (% of sites) | Crooked (# of sites) | Crooked (% of sites) |
|---|---|---|---|---|
| No vegetation | 129 | 26.93 | 60 | 17.91 |
| Very Light | 19 | 3.97 | 14 | 4.18 |
| Light | 89 | 18.58 | 54 | 16.12 |
| Light to Moderate | 52 | 10.86 | 43 | 12.84 |
| Moderate | 87 | 18.16 | 74 | 22.09 |
| Moderate to Heavy | 51 | 10.65 | 46 | 13.73 |
| Heavy | 39 | 8.14 | 32 | 9.55 |
| Very Heavy | 13 | 2.71 | 12 | 3.58 |
| TOTAL | 479 | 100.00 | 335 | 100.00 |
| **Density Category** | **Pickerel (# of sites)** | **Pickerel (% of sites)** | **Channel (# of sites)** | **Channel (% of sites)** |
| No vegetation | 68 | 50.37 | 1 | 11.11 |
| Very Light | 3 | 2.22 | 2 | 22.22 |
| Light | 33 | 24.44 | 2 | 22.22 |
| Light to Moderate | 7 | 5.19 | 2 | 22.22 |
| Moderate | 11 | 8.15 | 2 | 22.22 |
| Moderate to Heavy | 5 | 3.70 | 0 | 0.00 |
| Heavy | 7 | 5.19 | 0 | 0.00 |
| Very Heavy | 1 | 0.74 | 0 | 0.00 |
| TOTAL | 135 | 100.00 | 9 | 100.00 |

## Plant community mapping results:

Aquatic plant community mapping revealed that 1871 of the 3447 acres (~54%) of Crooked and Pickerel Lakes 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.) and submergent vegetation (muskgrass, pondweed, naiad, etc.). Of the 1576 acres of Crooked and Pickerel Lakes containing aquatic vegetation, the majority (~62%) consisted of submergent vegetation only, 35% was dominated by emergent vegetation, and the remaining 3% consisting of a mix of both submergent and emergent.

**Table 5.** Lake and vegetation type statistics.

| Lake and Vegetation | Surface Area (acres) | Percent of Total Surface Area |
|---|---|---|
| Crooked and Pickerel Lakes | 3446.97 | 100 |
| Little or no vegetation | 1871.26 | 54.29 |
| Aquatic vegetation: | 1575.71 | 45.71 |
| a. Emergent vegetation | 548.43 | 34.78* |
| b. Submergent vegetation | 980.29 | 62.17* |
| c. Mixed vegetation | 48.16 | 3.05* |

*refers to percent of surface area with aquatic vegetation (i.e., 1576 acres).

Bulrush-dominated plant communities were the most extensive, covering 488 acres of the vegetated areas in Crooked and Pickerel Lakes (Table 6). Reflecting sample site data, muskgrass, slender naiad, and eel-grass also commonly dominated plant communities. A mix of muskgrass and slender naiad as co-dominants accounted for 278 acres, followed by solely muskgrass-dominated communities at 178 acres. Eel-grass-dominated communities covered 153 acres. Dominant plant communities in Crooked Lake were similar to those of both lakes combined. However, Pickerel Lake differed in that mixed communities (of multiple co-dominant species) and pond-lilies were more prevalent, commonly dominating plant communities whereas slender naiad did not.

The aquatic plant communities of Crooked and Pickerel Lakes predominantly contained light to moderate-density growth. Approximately 76% of vegetated areas had densities in the light, light-moderate, or moderate categories (Table 7). Moderate-heavy, heavy, and very heavy-density growth covered the remaining 24% of vegetated areas. Data from individual lakes show the same patterns, though heavy-density growth was more extensive in Crooked Lake (Figure 7). Very heavy growth was documented only in Crooked Lake, but limited to less than 17 acres.

**Table 6.** Dominant aquatic plant community types: acreage.

| Dominant Community | Both Lakes (acres) | Both Lakes (percent) | Crooked (acres) | Crooked (percent) |
|---|---|---|---|---|
| Little or no vegetation | 1871.26 | 54.29 | 1045.75 | 44.48 |
| Bladderwort | 12.18 | 0.35 | 12.18 | 0.52 |
| Bulrush | 487.82 | 14.15 | 346.52 | 14.74 |
| Eel-grass | 153.14 | 4.44 | 146.13 | 6.21 |
| Eel-grass mix | 77.15 | 2.24 | 71.58 | 3.04 |
| Mixed emergents | 21.05 | 0.61 | 10.30 | 0.44 |
| Mixed submergents | 120.91 | 3.51 | 56.78 | 2.42 |
| Mixed submergents and emergents | 70.67 | 2.05 | 65.41 | 2.78 |
| Muskgrass | 178.36 | 5.17 | 159.21 | 6.77 |
| Muskgrass and Naiad | 278.25 | 8.07 | 278.25 | 11.83 |
| Muskgrass mix | 3.66 | 0.11 | 3.66 | 0.16 |
| Naiad | 66.99 | 1.94 | 66.99 | 2.85 |
| Naiad mix | 15.44 | 0.45 | 15.44 | 0.66 |
| Pond-lily | 12.10 | 0.35 | 2.66 | 0.11 |
| Pondweed | 7.17 | 0.21 | 3.89 | 0.17 |
| Pondweed mix | 12.84 | 0.37 | 9.47 | 0.40 |
| Swaying bulrush | 2.84 | 0.08 | 1.88 | 0.08 |
| Sweet gale | 2.08 | 0.06 | 2.08 | 0.09 |
| Watermilfoil | 53.07 | 1.54 | 53.05 | 2.26 |
| TOTAL | 3446.97 | 100.00 | 2351.22 | 100.00 |
| **Dominant Community** | **Pickerel (acres)** | **Pickerel (percent)** | **Channel (acres)** | **Channel (percent)** |
| Little or no vegetation | 819.98 | 75.75 | 5.52 | 41.71 |
| Bulrush | 140.93 | 13.02 | 0.37 | 2.79 |
| Eel-grass | 5.88 | 0.54 | 1.13 | 8.53 |
| Eel-grass mix | 4.49 | 0.41 | 1.08 | 8.12 |
| Mixed emergents | 9.69 | 0.89 | 1.07 | 8.06 |
| Mixed submergents | 63.61 | 5.88 | 0.52 | 3.94 |
| Mixed submergents and emergents | 5.26 | 0.49 | 0.00 | 0.00 |
| Muskgrass | 18.99 | 1.75 | 0.15 | 1.16 |
| Pond-lily | 7.71 | 0.71 | 1.73 | 13.04 |
| Pondweed | 2.85 | 0.26 | 0.43 | 3.26 |
| Pondweed mix | 2.13 | 0.20 | 1.24 | 9.38 |
| Swaying bulrush | 0.96 | 0.09 | 0.00 | 0.00 |
| Watermilfoil | 0.02 | 0.00 | 0.00 | 0.00 |
| TOTAL | 1082.50 | 100.00 | 13.25 | 100.00 |

**Table 7.** Aquatic plant community densities: acreage.

| Density Category | Both Lakes (acres) | Both Lakes (percent) | Crooked (acres) | Crooked (percent) |
|---|---|---|---|---|
| Very Light | 4.86 | 0.31 | 4.43 | 0.34 |
| Light | 296.17 | 18.78 | 234.31 | 17.95 |
| Light to Moderate | 429.65 | 27.25 | 321.42 | 24.62 |
| Moderate | 467.94 | 29.68 | 417.32 | 31.97 |
| Moderate to Heavy | 189.88 | 12.04 | 181.52 | 13.90 |
| Heavy | 171.47 | 10.87 | 129.56 | 9.92 |
| Very Heavy | 16.91 | 1.07 | 16.91 | 1.30 |
| TOTAL | 1576.88 | 100.00 | 1305.47 | 100.00 |
| **Density Category** | **Pickerel (acres)** | **Pickerel (percent)** | **Channel (acres)** | **Channel (percent)** |
| Very Light | 0.00 | 0.00 | 0.43 | 5.60 |
| Light | 57.66 | 21.87 | 4.20 | 54.46 |
| Light to Moderate | 106.79 | 40.50 | 1.43 | 18.53 |
| Moderate | 49.19 | 18.66 | 1.43 | 18.55 |
| Moderate to Heavy | 8.36 | 3.17 | 0.00 | 0.00 |
| Heavy | 41.69 | 15.81 | 0.22 | 2.86 |
| Very Heavy | 0.00 | 0.00 | 0.00 | 0.00 |
| TOTAL | 263.69 | 100.00 | 7.72 | 100.00 |

**Figure 7.** Map of aquatic plant community types in Crooked and Pickerel Lakes.

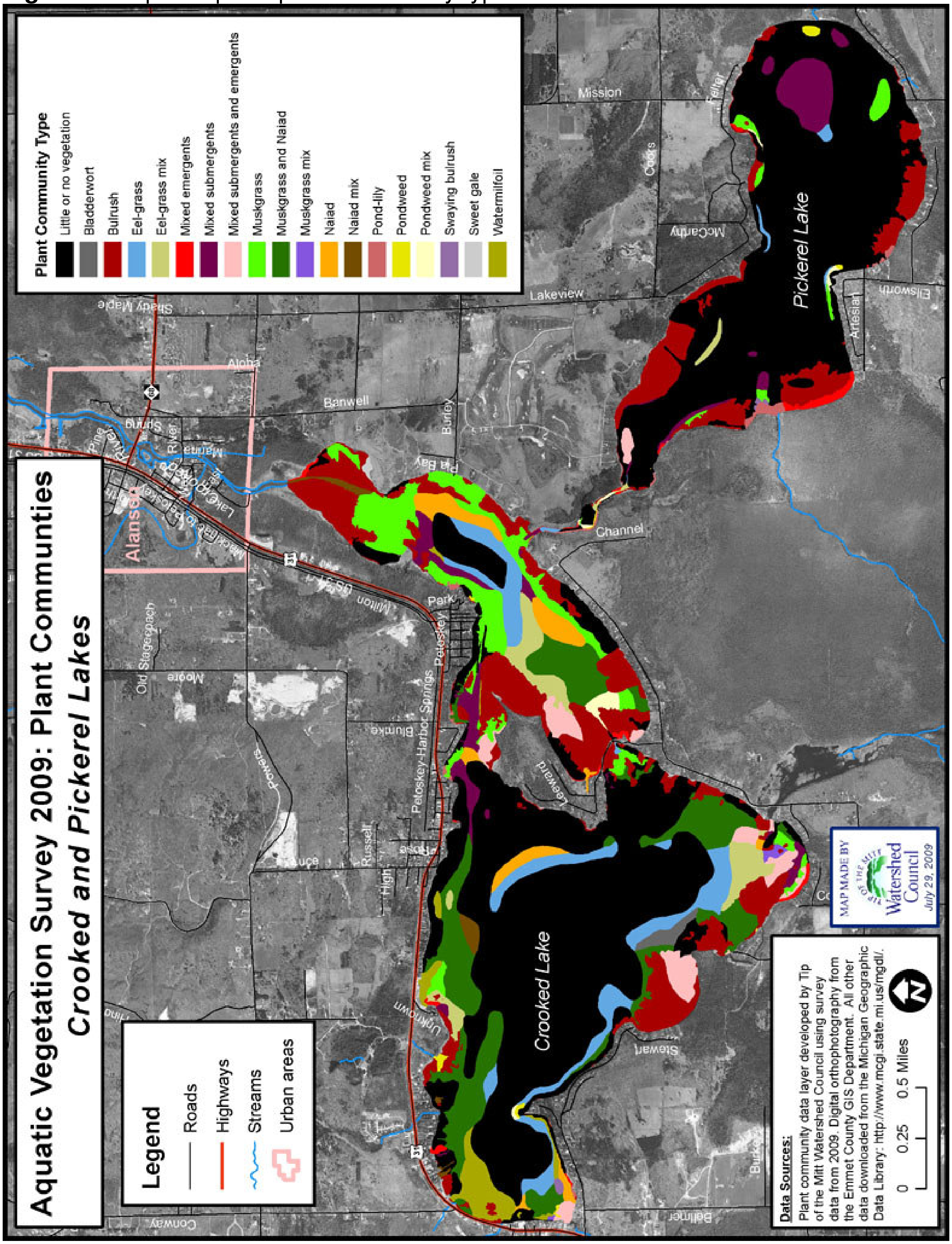
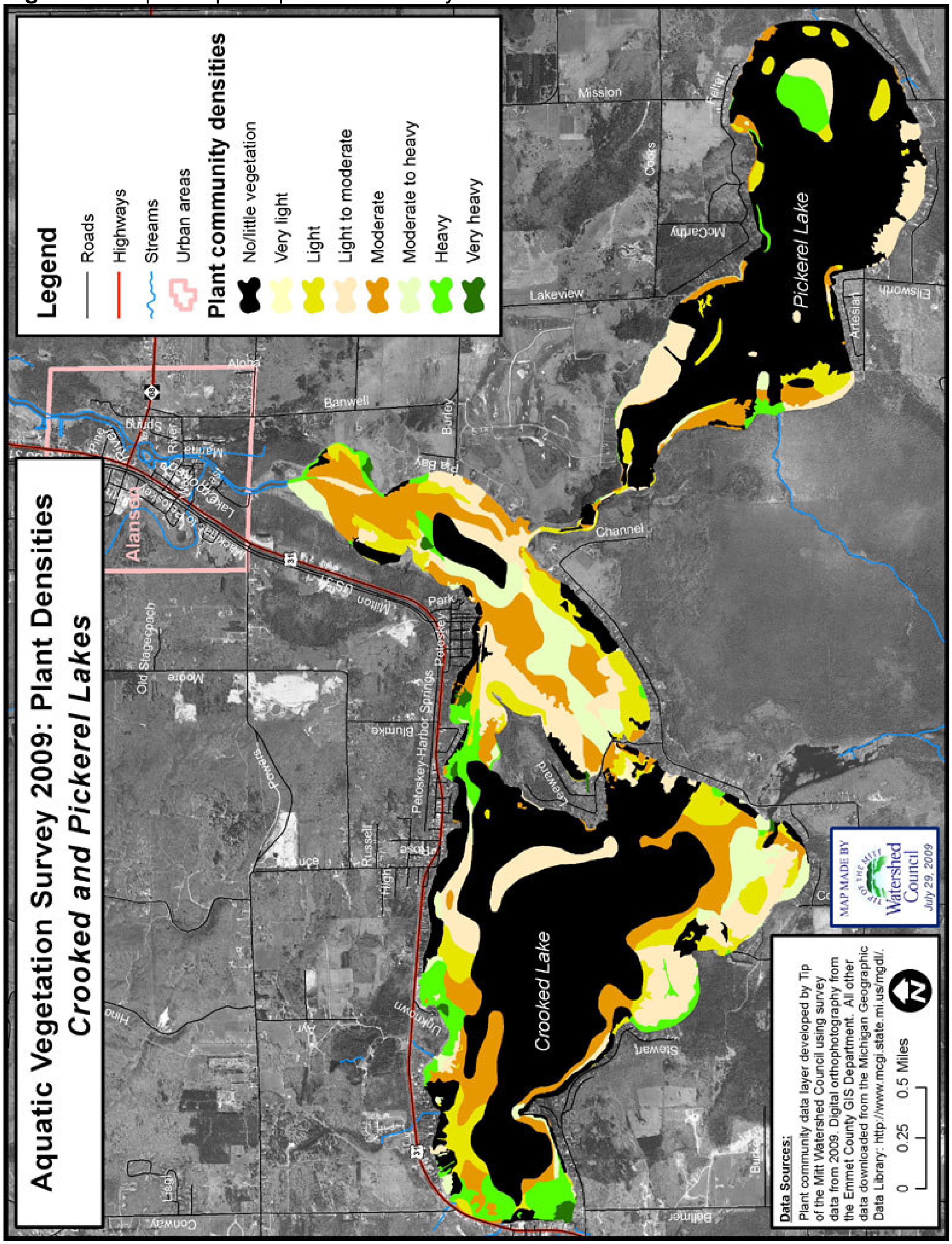


**Figure 8.** Map of aquatic plant community densities in Crooked and Pickerel Lakes.



# DISCUSSION

## General

Survey results revealed that large areas of Crooked and Pickerel Lakes contain little or no vegetation and that a diverse assemblage of native plant species exists in the lakes. In terms of surface area, over 54% of the lakes contain little or no vegetation, though this statistic varies widely between lakes; ranging from 45% without vegetation in Crooked Lake to 75% in Pickerel Lake. A total of 31 aquatic plant taxa were documented during the survey, which ranks Crooked and Pickerel Lakes in the middle for aquatic plant diversity in lakes surveyed by the Watershed Council (Table 8). However, the averaged diversity across all sample sites in Crooked and Pickerel Lakes (2.4 taxa/site) was among the lowest.

**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 |
| Crooked/Pickerel | 3,447 | 70 | 46% | 31 | 2.4 |
| Long | 398 | 61 | 24% | 26 | 2.8 |
| 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 Crooked and Pickerel Lakes. 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 Crooked and Pickerel Lakes, extensive areas in the deeper basins with depths exceeding 20 feet contained little or no vegetation (Figure 6). As evidenced in aquatic plant surveys on 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 was apparent in the east basin of Pickerel Lake, where little vegetation was found along the eastern shore. However, most of the eastern end of Crooked Lake did contain aquatic plant life. The location of

Oden Island probably contributes to the atypical aquatic plant growth in the east end of Crooked Lake because it intercepts the force of wind and waves that would otherwise push against the eastern shoreline. The lack of aquatic vegetation on the west side of Oden Island is indicative of the typical pattern of lightly vegetated areas on the east ends of the region's lakes. Vegetated areas along the eastern shores as well as areas of little or no vegetation spread throughout both lakes points out that other factors beyond depth and prevailing winds contribute to vegetated lake areas, such as substrate types, nutrient availability, water clarity, and water currents.

Most of the vegetated areas in Crooked and Pickerel Lakes contain light to moderate-density plant communities. Limited areas in Crooked Lake and none in Pickerel Lake contain what is generally considered to be nuisance plant growth. Areas of dense vegetation in Crooked Lake classified as very heavy were limited to the southwest corner and in two locations along the northern shore. The heavy growth in the southwest corner is probably caused principally by natural factors; namely the inlet stream (Round Creek) coupled with extensive shallow areas. Streams typically contain higher concentrations of nutrients than lakes, which often results in heavy-density plant growth in the lake areas they flow into. However, unnaturally elevated nutrient inputs from residential and commercial development of shoreline areas could also be contributing to the heavy plant growth in the southwest corner of the lake. The pockets of heavy-density growth along the northern shoreline may also be the result of nutrient pollution from nearby shoreline properties.

Due to a lack of historical data, being that this was the first comprehensive aquatic plant survey to be performed on Crooked and Pickerel Lakes, it was not possible to examine trends or changes in the aquatic plant communities. Factors that typically cause changes in plant growth include aquatic plant management efforts, increased nutrient availability, and ecosystem changes caused by non-native species. Nutrient inputs from cultural (human) sources, such as fertilizers, septic leachate, and stormwater, may have increased over time, though data from Tip of the Mitt Watershed Council monitoring programs do not show increases in nutrient concentrations in open water. Zebra mussels, which are present in both lakes, might be causing changes that have resulted in increased aquatic plant growth. Increased water clarity evident in the data from Pickerel Lake is probably a result of zebra mussels feeding on phytoplanktonic algae, which would increase both nutrient and habitat availability for higher aquatic plants.

**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 inform the public about problems occurring in the lake and progress of the Lake Association's efforts at aquatic plant and lake management. An informed public will be more supportive of the Association's efforts to manage the lake ecosystem and its aquatic plants. 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 Lake Association should consider developing an aquatic plant management plan to enhance lake management efforts over the long-term. The aquatic plant community is a vital component of the aquatic ecosystem, such that good aquatic plant management translates to good lake ecosystem management. 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.

3. Investigate potential nutrient pollution issues. Nutrient pollution can lead to excessive plant growth and should be controlled wherever and whenever possible. A shoreline survey provides valuable information regarding locations and potential sources of nutrient pollution. In addition, information gathered from a shoreline survey can be used to work with lakeshore property owners to verify nutrient pollution, identify sources, and correct any problems. According to

Watershed Council records, a shoreline survey has not been conducted on Crooked and Pickerel Lakes since 1988. Therefore, it is recommended that the Lake Association sponsor another shoreline survey to document current conditions and address any problem areas. In the meantime, the Lake Association can make positive steps toward controlling nutrient pollution by communicating and working with shoreline property owners. In particular, property owners around the lake should be encouraged to properly maintain septic systems, replace old or failing septic systems (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 (with rain gardens, grassy swales, retention ponds, or other methods for treating the stormwater).

4. Continue using manual removal methods for controlling curly-leaf pondweed infestations. Curly-leaf pondweed, an invasive species, was documented at only one site during this survey; at the mouth of Oden (Hatchery) Creek on the north shore of Crooked Lake. Upon being notified of the problem, the Lake Association took immediate steps to control the growth and spread of the curly-leaf pondweed infestation by manually removing and disposing of the invasive plants found in that area. For these circumstances manual removal is preferred because it is adequate for controlling small curly-leaf pondweed infestations and has minimal impacts on the lake ecosystem. The Lake Association should return frequently to the location of this infestation to assess efforts and continue with manual removal when necessary. Additionally, the Association should regularly survey other lake areas for the presence of curly-leaf pondweed and implement control measures as necessary to prevent the spread of this invasive species.

5. Preserve the lake ecosystem and natural diversity. Nuisance aquatic plant growth, both native and non-native, is an issue of concern for many shoreline residents and other lake users. Although an invasive species has been found,

most of the vegetated lake area contains a vibrant, healthy aquatic plant population. 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 for sustaining a healthy fishery and maintaining a healthy aquatic ecosystem.

6. Educate and inform lake users. Human activity in a multitude of forms typically has the greatest impact on a lake's aquatic plant communities. Therefore, effectively managing the lake's aquatic plants requires information and education outreach projects that target shoreline property owners, watershed residents and all 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.

7. Regularly survey the aquatic plants of Crooked and Pickerel Lakes. To effectively manage the aquatic plant community of Crooked and Pickerel Lakes, periodic aquatic plant surveys should be conducted. Future surveys will provide the necessary 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.

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