Sentinel Lake Assessment Report
Cedar Lake (49-0140)
Morrison County, Minnesota

Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit
&
Minnesota Department of Natural Resources
Section of Fisheries
November 2010

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wq-2slice49-0140

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Executive Summary

The Minnesota Pollution Control Agency (MPCA) is working in partnership with the Minnesota Department of Natural Resources (MDNR) on the Sustaining Lakes in a Changing Environment (SLICE) Sentinel Lakes Program. The focus of this interdisciplinary effort is to improve understanding of how major drivers of change such as development, agriculture, climate change, and invasive species can affect lake habitats and fish populations, and to develop a long-term strategy to collect the necessary information to detect undesirable changes in Minnesota Lakes (Valley 2009). To increase our ability to predict the consequences of land cover and climate change on lake habitats, SLICE utilizes intensive lake monitoring strategies on a wide range of representative Minnesota lakes. This includes analyzing relevant land cover and land use, identifying climate stressors, and monitoring the effects on the lake's habitat and biological communities.

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). The "deep" lakes typically stratify during the summer months only. "Shallow" lakes are defined as mixing continuously throughout the summer. "Cold water" lakes are defined as lakes that either harbor cisco, lake whitefish, or lake trout and are the focus of research funded by the Environment and Natural Resource Trust Fund (ENRTF). "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is also funded by the ENRTF.

Cedar Lake was selected to represent a cold water, deep lake in the North Central Hardwood Forests (NCHF) ecoregion. Cedar Lake is a 96 hectare (236 acre lake), located near Upsala, Minnesota in Morrison County, within the Mississippi River (Sartell) watershed. The lake has a maximum depth of 26.8 meters (88 feet) and a mean depth of 11.9 meters (39 feet). The lake is 28% littoral with one public access on the south shore of the lake. The total contributing watershed for Cedar Lake is 552 hectares (1,363 acres). Cedar Lake was a reference lake for NCHF ecoregion reference condition development in the mid 1980s (Heiskary and Wilson, 2005).

Cedar Lake is a deep lake that stratifies early in the summer and remains stratified until mid-October or later. It fully mixes in fall and in the spring, following ice-out. Based on recent water quality data (2008-2010), Cedar Lake is considered to be mesotrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 13 micrograms per liter (µg/L), 2.9 µg/L, and 4.3 meters (14.1 feet) respectively. TP is better than the typical ranges (based on reference lakes) for NCHF Ecoregion. Nuisance algal blooms were not observed and transparency was typically high during much of the summer. Trophic status data collected since 2000 suggest declining TP and chl-*a* over the past decade. Based on these data, Cedar Lake is considered to be fully supporting aquatic recreation use.

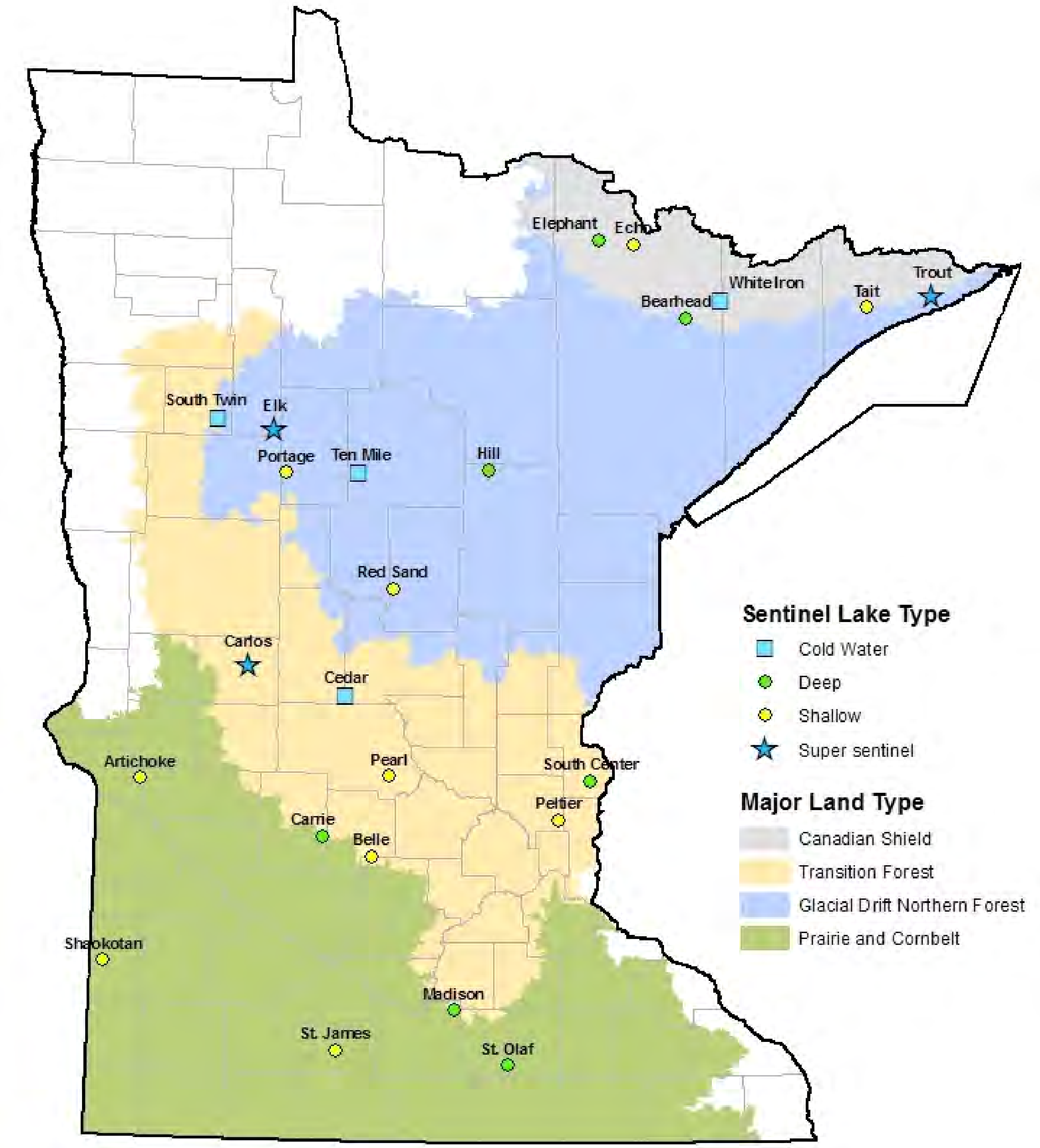
The fish community of Cedar Lake is quite diverse with several species intolerant to pollution including two state-listed species of greatest conservation need (pugnose shiners and least darters). Perhaps due in part to restricted harvest regulations and quality habitat conditions, northern pike and walleye populations have improved over time with significant numbers of large individuals of both species. Recent improvements in size are also apparent with bluegill and crappie populations as well. Still, the status of two native fish species to Cedar Lake remain uncertain and should be a source of further investigation: 1) potential mechanisms explaining high abundance of small largemouth bass despite high quality largemouth bass habitat and presumably low angler harvest throughout Cedar's surveyed history; and 2) current population status of cisco; a high-energy cold-water forage fish. Despite habitat that is suitable year-round for cisco, they have been difficult to sample with targeted gears. Additional sampling during periods of greatest vulnerability may be needed to ascertain cisco population status in the lake.

Aquatic plants in Cedar Lake are diverse, grow to deep depths (7.5 meters), and contribute to the lake's resilience as a clear-water lake and high quality fishery. Although the invasive curly-leaf pondweed is present in the lake, the lake's low nutrient levels, clear-water, and abundant native aquatic plants has presumably prevented this plant from growing abundantly and thus having harmful ecological effects.

Keeping watershed nutrient loading and aquatic plant removal at low levels will be important for keeping curly-leaf pondweed in check and maintaining quality habitat conditions.

An ecoregion-based eutrophication model was used to predict in-lake TP based on Cedar Lake's size, depth, and watershed area using inputs the NCHF ecoregion. The model predicted in-lake TP at 20 µg/L, which is higher than the observed 13 µg/L (but within the error of model prediction). A separate subroutine within the model estimated "background" TP for the lake at 18 µg/L. The model predictions, along with the overall assessment of Cedar Lake's water quality data, clearly indicate the lake's water quality is better than anticipated for a lake of this size in this portion of the State.

Figure 1: Sentinel lakes and major land types



Introduction

This report provides a relatively comprehensive analysis of physical, water quality and ecological characteristics of Cedar Lake in Morrison County, Minnesota (MN). This assessment was compiled based on Minnesota Department of Natural Resources (MDNR) surveys of the lake's fish and aquatic plant communities, Minnesota Pollution Control Agency (MPCA) and volunteer water quality monitoring, and analysis of various other sources of data for the lake. The water quality assessment focuses on data collected during the 2008-2010 seasons; however, historical data are used to provide perspective on variability and trends in water quality. Water quality data analyzed will include all available data in STORET, the national repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

1910's – 1940's	Initial stocking of "bass, panfish, and pike." Two hundred pounds of carp removed from a trap in 1949. Carp not sampled again until 2000 and a small remnant population persists. Downstream connection to the Mississippi River is the presumed source of periodic migrants.
1950's – 1960's	Largemouth bass, northern pike, and walleye stocked irregularly; initial lake survey completed in 1959 documenting 19 cottages on the lake.
1980's – 1990's	Cedar Lake sampled in 1985 and 1986 as an ecoregion reference lake by MPCA. Sixteen cottages recorded on the lake during the 1983 survey.
1996	Permit for an offshore heat exchanger for geothermal heating and cooling of Camp Lebanon authorized by the DNR Division of Waters. Lack of rule language regulating this type of use of a public water and controversy over the permits issuance precipitated a revision to MN Rule 6115 (Public Water Resources) Section 0211, Subpart 6B (Energy Exchangers) that now regulates this type of use of a public water. To date the system remains operational with little documented environmental or recreational impact to the lake.
2000's	Biennial walleye fry stocking (2001-2005). "Conservation" harvest regulations implemented to protect quality northern pike, walleye, and crappie populations (2002). Walleye stocking regime changed to fingerlings due to poor survival (2005). First documented occurrence of invasive curly-leaf pondweed during reconnaissance surveys; date of actual introduction presumably years earlier (2005). Public boat launch installed (2005). The lakeshore is lightly developed with 12 homes/cabins, one bible camp, and a 50 site public campground and beach.

Summary of human activities and past study of Cedar Lake

Lakeshore development is light with only 12 cabins/homes present on the lake in addition to the Camp Lebanon Bible Camp and Cedar Lake Memorial Park, which consists of 50 campsites. The lake experiences significant recreational use due to attractive features such as clear water and the beach areas found at the bible camp and campground. Much of the south shoreline remains undeveloped due to the close proximity of County Road 19. The Pine/Cedar Lake Association maintains an active interest in the management of the lake. Members of this group participate in the placement of signs to protect a large bulrush bed on the northeast side of the lake and also a dark-bottomed bay near the bible camp. This bay is posted (no fishing) each spring to protect vulnerable concentrations of black crappie. The lake association had been supportive of fish management activities such as MDNR initiated fishing regulations, habitat protection, stocking and the Sentinel Lakes Program. The MDNR

Aquatic Plant Management Program has not received any applications for removal of aquatic plants on Cedar Lake. Continued protection of aquatic plant cover and vegetated shoreland will be important for maintaining the resilience and integrity of Cedar Lake habitats and fish communities (DNR, 2009). Cedar Lake was one of 90 lakes selected to represent minimally impacted reference conditions for the four major ecoregions that contain over 90 percent of Minnesota lakes. These lakes were selected based on having a watershed land use that was typical of the ecoregion and were considered to be minimally impacted by point and nonpoint source pollution (lakes with known point sources, major urban areas, and/or major feedlots were excluded). Fisheries classification, maximum depth, mixing status, and surface area were also considerations in the selection of reference lakes (Heiskary and Wilson, 2005). These lakes were sampled 3-4 times per summer from 1985 to 1987. Cedar Lake, specifically, was sampled in 1985 and 1986 and that data contributes to this current assessment.

Background

Lake Morphometric and Watershed Characteristics

Cedar Lake is on the border of Morrison and Todd counties within the Mississippi River (Sartell) watershed. Cedar Lake is located near Upsala, MN. A public access is located on the south shore. Cedar Lake is deep and dimictic (mixing in spring and fall, stratified in summer).

Cedar Lake's morphometric characteristics are summarized in Table 1. Percent littoral area refers to that portion of the lake that is 4.6 meters (m; 15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake (Figure 2). Lakes with a high percentage of littoral area often have extensive rooted plant (macrophyte) beds. These plant beds are a natural part of the ecology of these lakes and are important to maintain and protect.

Table 1: Cedar Lake and watershed morphometric characteristics

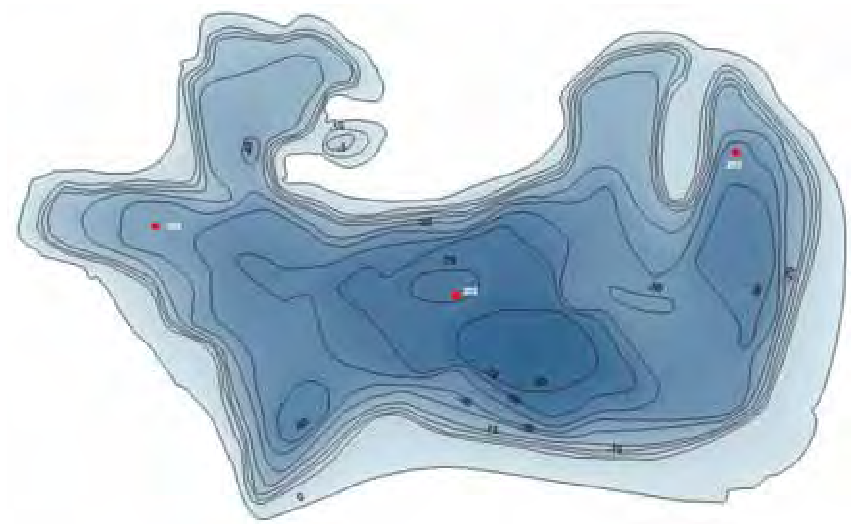
Lake Name	Lake ID	[1]Lake Basin	[2]Lake Basin	[2]Littoral Area	Total Watershed Area	Watershed: Lake	[2]Max. Depth	[2]Mean Depth	Lake Volume
		Hectares (Acres)	Hectares (Acres)	%	Hectares (Acres)	Ratio	Meters (Feet)	Meters (Feet)	Acre-Ft.
Cedar	49-0140	100 (248)	96 (236)	28	552 (1,363)	5.7 : 1	26.8 (88)	11.9 (39)	8,880

The lake's watershed has one drainage point located on the south shore of the lake empting into North Two River. The contributing watershed has a total area of 552 hectares (1,363 acres) resulting in a watershed-to-lake area ratio of approximately 5.7:1. Watershed areas were estimated based on data from the MDNR Catchment layer.

Soils found near Cedar Lake are from the Cushing-DeMontreville-Mahtomedi series. These soils tend to be sandy soils of the hardwood forests that were formed from glacial till and outwash (Arneman 1963).

[1] Based on the Protected Waters Inventory, MDNR
[2] Based on the 2009 1:100,000 Lakes and Rivers Coverage, MDNR

Figure 2: Cedar Lake monitoring sites and bathymetry (based on 2008 MDNR acoustic survey)



Lake Mixing and Stratification

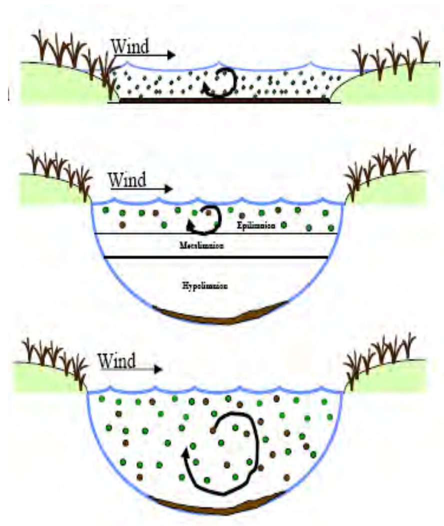
Lake depth and mixing has a significant influence on lake processes and water quality. *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 9 meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 3). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of 6 meters or less) in contrast, typically do not stratify and are often referred to as *polymictic*. Lakes, with moderate depths, may stratify intermittently during calm periods, but mix during heavy winds and during spring and fall. Measurement of temperature throughout the water column (surface to bottom) at selected intervals (e.g. every meter) can be used to determine whether the lake is well-mixed or stratified. The depth of the thermocline (zone of maximum change in temperature over the depth interval) can also be determined. In general, dimictic lakes have an upper, well-mixed layer (epilimnion) that is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. This low oxygen environments in the hypolimnion are conducive to total phosphorus (TP) being released from the lake sediments. During stratification, dense colder hypolimnetic waters are separated from the nutrient hungry algae in the epilimnion. Intermittently (weakly) stratified polymictic lakes are mixed in high winds and during spring and fall. Mixing events allow for the nutrient rich sediments to be re-suspended and are available to algae.

Figure 3. Lake stratification

Polymictic Lake
Shallow, no layers,
Mixes continuously
Spring, Summer & Fall

Dimictic Lake
Deep, form layers,
Mixes Spring/Fall

Intermittently Stratified
Moderately deep
Mixes during high winds
Spring, Summer, & Fall



Ecoregion and Land Use Characteristics

Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Cedar Lake lies within the North Central Hardwood Forests (NCHF) ecoregion (Figure 4). NCHF values will be used for land use (Table 2), summer-mean water quality comparisons (Table 7), and in the model application.

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Land use within the watershed is dominated by forested land uses. Pasture, water/wetland, and cultivated land uses each make up approximately 20% of the total land use while developed area makes up only 3% of the watershed (Figure 5).

Figure 4: Minnesota ecoregions as mapped by United States Environmental Protection Agency

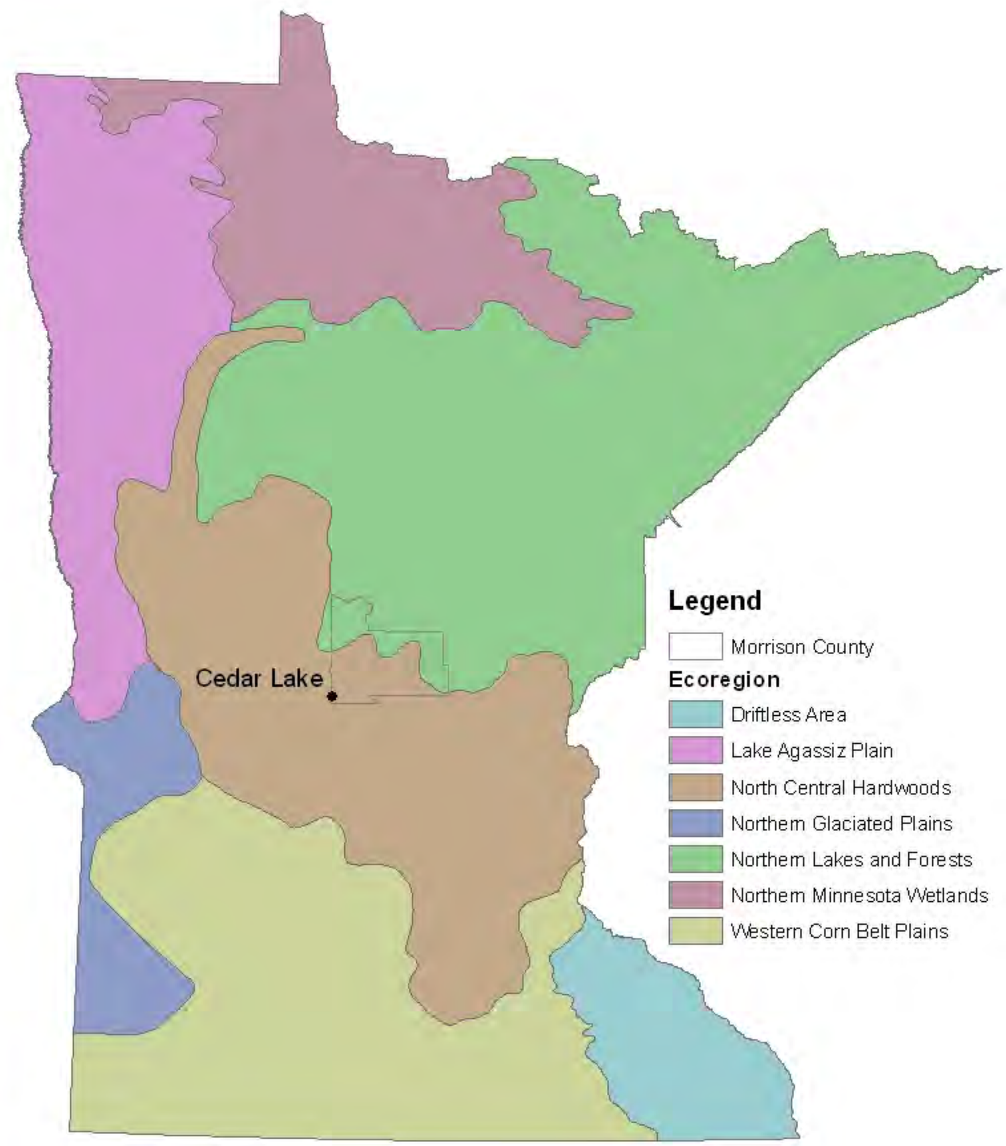


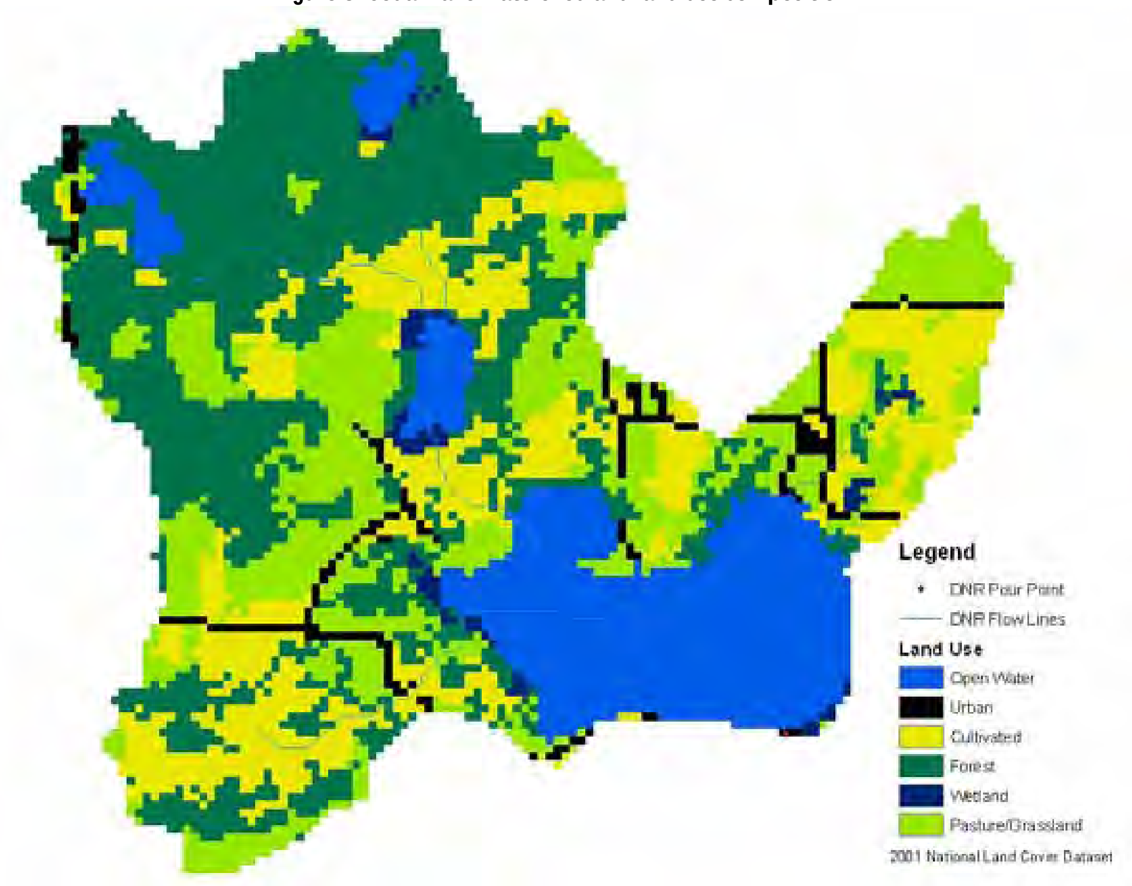
Table 2: Cedar Lake ecoregion land use comparison

Typical (interquartile) range based on 35 NCHF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	NCHF ecoregion	Cedar (1969)[2]	Cedar (1991)[3]	Cedar(2001)[1]
Developed	2 - 9	0	0	3
Cultivated (Ag)	22 - 50	8	22	20
Pasture & Open	11 - 25	29	13	22
Forest	6 – 25	44	46	35
Water & Wetland	14 - 30	19	19	20

[1]National Land Cover Database www.mrlc.gov/index.php
[2]Minnesota Land Management Information Center http://www.mngeo.state.mn.us/chouse/metadata/luse69.html
[3]Minnesota Land Cover 1991-1992:MAP http://www.mngeo.state.mn.us/chouse/land_use_DNRmap.html

Figure 5: Cedar Lake watershed and land use composition

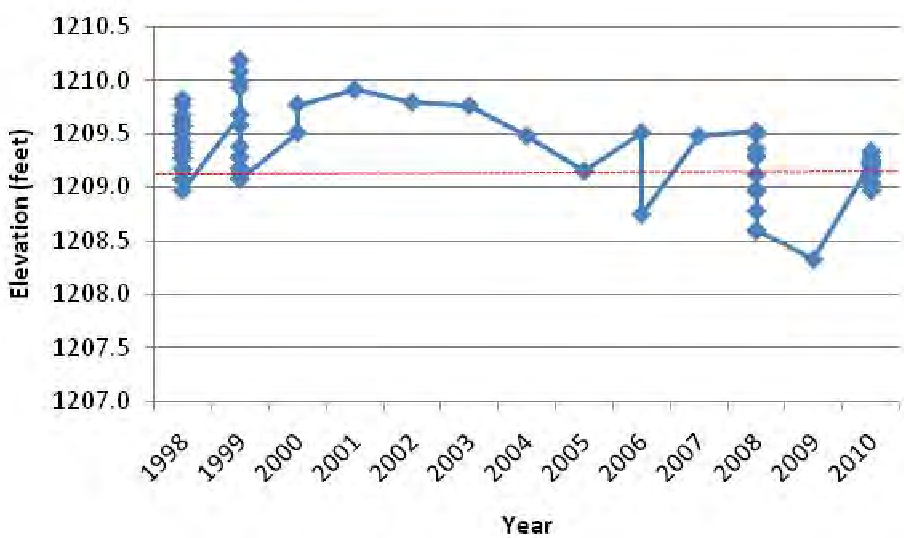


Lake Level and Ice On/Off

The MDNR Division of Waters has been measuring water levels intermittently on Cedar Lake since 1959. During the period of record (1972 – 2009), the lake has varied by 1.85 feet, based on 79 readings. The highest and lowest recorded elevations are 1210.18 feet on 08/17/1999 and 1208.33 feet on 05/24/2009, respectively. The record is spotty until 1998 and 1999, when a consistent record is available; from 2002 to present at least an annual reading is available. The ordinary high water mark (OHW) for Cedar Lake is 1209.33 feet (Figure 6). Based on the recent record, peak water levels were noted in 1999 with a decline to May of 2009. Lake levels increased in 2010, consistent with increased precipitation (Figure 7). The complete water level record may be obtained from the MDNR web site at: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=49014000.

Ice-on records for Cedar Lake, dating back to 1994, indicate that ice has typically formed by late November to mid-December. November 20, 1997 is the earliest recorded ice-on date and December 22, 1998 is the latest ice-on date. The ice is historically off of Cedar Lake by mid-April. April 28, 1996 is the latest ice-off date while March 25, 2000 is the earliest ice-off date on record (Appendix A).

Figure 6: Cedar Lake water level (OHW in red)



Precipitation and Climate Summary

Rain gage records from Holdingford, MN show five, one-inch plus rain events during summer 2008, two in the summer of 2009, and eight in the summer of 2010 (Figure 7). Large rain events may increase runoff into the lake and may influence in-lake water quality and lake levels. This will be considered in the discussion of lake water quality for Cedar Lake. Precipitation records for the 2008 and 2009 water years (October 2007 through September 2008 and October 2008 through September 2009, respectively) showed normal amounts of rainfall were received (Figure 8). The long-term summer (April to October) rain fall amounts exhibit an increase from 1850 to present (Figure 9). Lake level can respond to these changes in precipitation; though there may be a lag in this response. Changes in precipitation over time have a distinct affect on groundwater levels, which are very important in lake level regulation in lakes with small watershed: lake ratios like Cedar Lake.

Figure 7: Summer (April to October) 2008-2010 rainfall based on records for Holdingford, MN

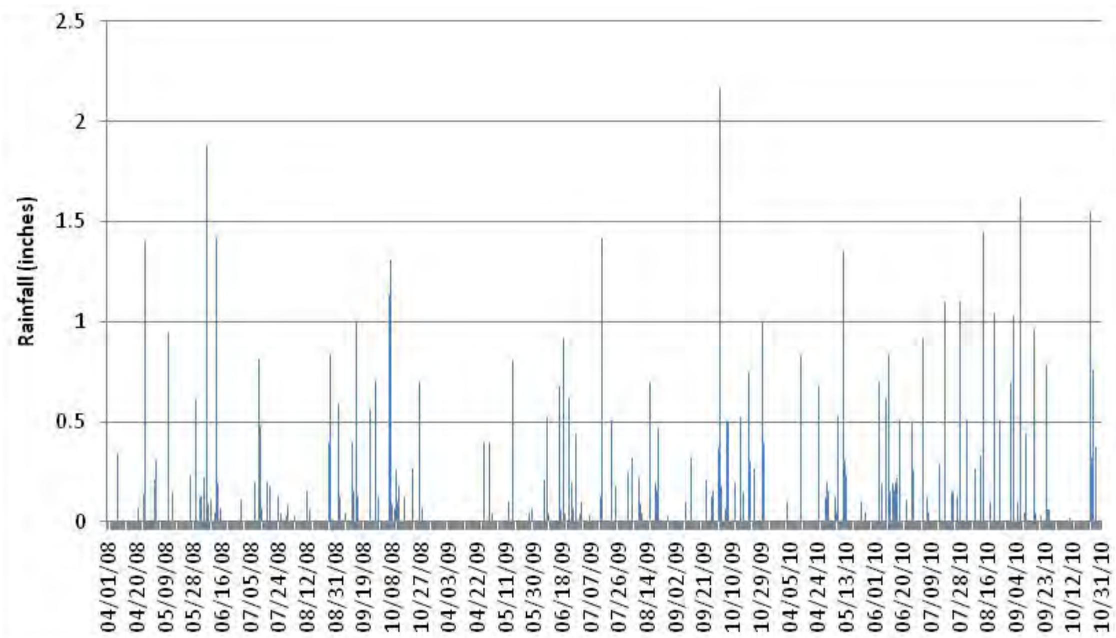
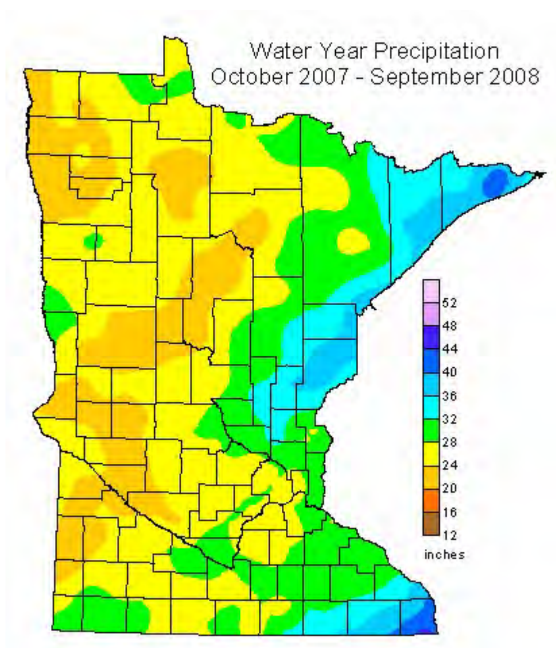


Figure 8: 2008 Minnesota water year precipitation and departure from normal

Prepared by State Climatology Office, MDNR

Values are in inches



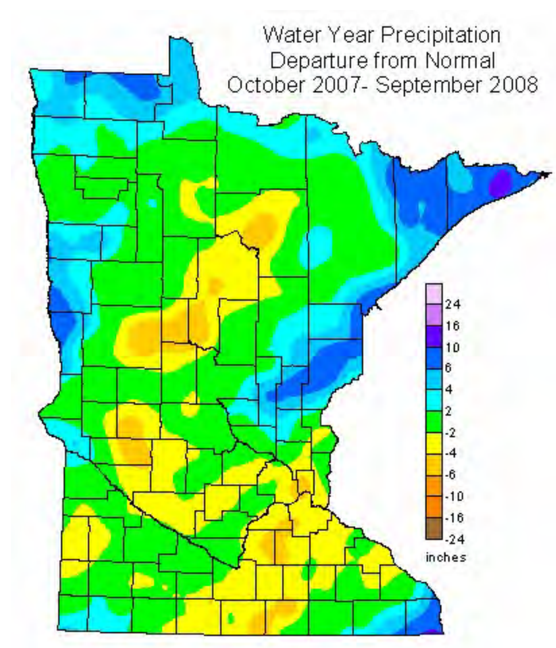
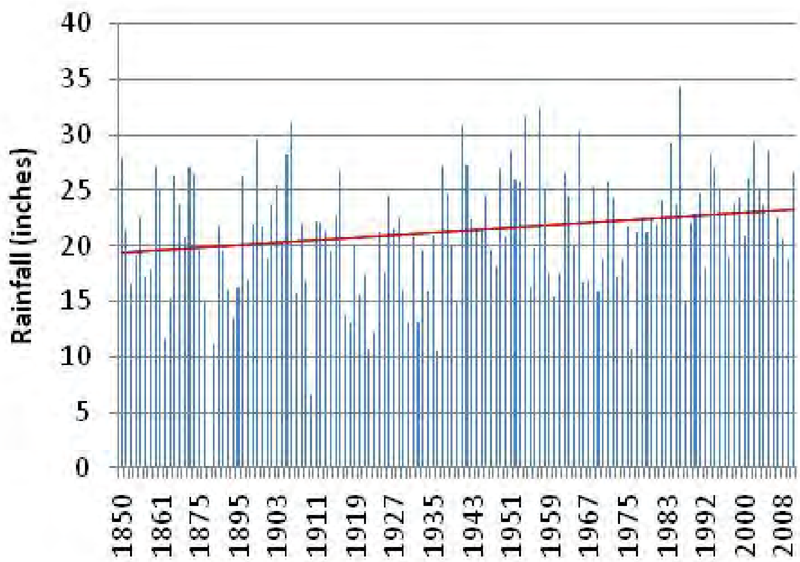


Figure 9: Historical summer (April to October) precipitation trends based on records for Holdingford, MN. Mean for period of record indicated by solid blue line and simple linear regression by red dashed line.



Methods

Fisheries and Aquatic Plants

Frequency of occurrence of aquatic plant species were assessed using the point-intercept method (Madsen 1999). This method entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately 1 m, then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80 m (0.7 points per littoral acre). Hydroacoustics were used to survey vegetation biovolume (percent of water column occupied by vegetation) along 40 m transects using methods and equipment described by Valley et al. (2005). Local kriging with VESPER 1.6 was used to create 15 m raster grids of biovolume (Walter et al. 2001; Minasny et al. 2002).

Most recent fisheries surveys follow guidelines outlined by MDNR Special Publication 147 (1993; Manual of Instructions for Lake Survey). Fish community integrity surveys were also completed on each Sentinel lake following methods described by Drake and Pereira (2002).

Water Quality

Water quality data for Cedar Lake were collected monthly by MPCA staff. Bi-weekly dissolved oxygen (DO) and temperature profiles and Secchi disk measurements were collected by a volunteer. Lake surface samples were collected by MPCA staff with an integrated sampler, a polyvinyl chloride (PVC) tube 2 meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (1.24 inches). Zooplankton samples were collected with an 80 micrometer mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth TP samples were collected with a Kemmerer sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples were collected at site 202 (Figure 2). Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf .

Laboratory analysis was performed by the Minnesota Department of Health using United States Environmental Protection Agency-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride, metals, and chl-*a*. Phytoplankton samples were analyzed at the MPCA using a rapid assessment technique.

Zooplankton

Zooplankton samples were collected monthly from May to October 2008 through 2010. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 meter of the bottom and withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100% reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 µg/L mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5 milliliter aliquot. A 5 milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level), and measured to the nearest 0.01 millimeter using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick 1994 in Hirsch 2009).

Results and Discussion

Fisheries Assessment

MDNR fisheries managers utilize netting survey information to assess the status of fish communities and measure the efficacy of management programs. Presence, absence, abundance, physical condition of captured fishes, and community relationships among fish species within survey catch information also provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). This data is stored in a long-term fisheries survey database, which has proven valuable in qualifying and quantifying changes in environmental and fisheries characteristics over time.

In 2008 and 2009, survey crews assessed the biotic integrity of the fish community in Cedar Lake (Drake and Pereira 2002). Indices of biotic integrity (IBI) have been used for decades across North America to assess status of aquatic communities and to classify biotic impairments (Angermeier and Karr 1994). Although formal criteria have yet to be developed for classifying biotic impairments in Minnesota Lakes, IBI surveys from over 325 lakes across the state provide a good assessment of the range of conditions that might be expected in lakes of differing productivity.

IBI surveys were conducted in Cedar Lake in 2008 and 2009, and the IBI score was exceptionally high in both years at 131 and 113 respectively. As part of the SLICE program, IBI surveys will be repeated in 2010 and 2011 to evaluate the natural year to year fluctuations in scores and to help managers understand biologically significant changes in scores. Accordingly, an evaluation of whether an 18 point difference between 2008 and 2009 surveys is within the natural range of variability for IBI scores.

A high IBI score usually indicates a balanced and diverse fish community with a high proportion species intolerant to disturbance and a low proportion of tolerant ones. MDNR crews sampled seven species intolerant species and two state-listed species of special concern (pugnose shiner *Notropis anogenus* and least darter *Etheostoma microperca*). In addition, crews sampled blacknose shiners (*Notropis heterolepis*), banded killifish (*Fundulus diaphanus*), blackchin shiner (*Notropis heterodon*) and Iowa darter (*Etheostoma exile*) throughout the nearshore areas of the lake. These species have disappeared from many Twin City metropolitan lakes whose watersheds have been developed or hydrologically altered (Dodd 2009). Chara or muskgrass (*Chara* sp.) appears to provide important habitat for several intolerant littoral fish species (Valley et al. 2010) and is abundant in Cedar Lake. In addition to keeping nutrient additions to the lake low, protection of dense nearshore beds of chara will be important for protecting these species and the fish community integrity in general.

A small, presumed migrant population of common carp (*Cyprinus carpio*) from the Mississippi River has persisted in Cedar Lake throughout its surveyed history. However, carp populations typically do not fare well in deep, cool, clear-water lakes like Cedar, and thus should have minimal impacts on other fish species and habitats if high water quality persists.

Fisheries management of Cedar Lake has consisted of two primary practices, fish stocking and fishing regulations. The history of fish stocking on Cedar Lake dates back to 1910 with poorly documented stockings of bass, panfish, and pike occurring from 1910-1940. Walleye, largemouth bass, and northern pike were stocked irregularly from 1953 to 1967. No stocking took place from 1968 through 2000 due to the lack of a public access. Walleye stocking was re-initiated in 2001 as a state-owned public access was planned for installation in 2005. Walleye fry were stocked in 2001, 2003, and 2005. Fall electrofishing evaluations indicated little if any survival from these efforts, therefore walleye fingerlings were stocked during the same years. Fingerling stocking has proven effective in developing a desirable walleye population and sport fishery and has been continued.

Special fishing regulations were implemented in 2002 to help preserve fish populations expected to receive increased fishing pressure due to the opening of a public access. "Conservation Regulations" were employed consisting of the following regulations: northern pike – 1 m (40 inch) minimum size limit, 1 fish bag limit, walleye – 2 fish bag limit, black crappie – 5 fish bag limit. Cedar Lake had maintained a quality northern pike population throughout its history making it a good candidate for restrictive regulations. The lowered walleye bag limit was utilized to ensure establishment of an adequate population with renewed stocking efforts. Low catches in DNR gear and by anglers indicated a crappie population well below desired levels suggesting the bag limit reduction may be helpful in reviving the population in the face of increasing fishing pressure.

Since 1959, DNR Fisheries has used a variety of sampling techniques to assess fish populations on Cedar Lake. Lake surveys were completed in 1959, 1983, 1994, and 2006. Population assessments were performed in 1988 and 2000. Additional fish sampling has included: spring trapnet assessments targeting northern pike in 1995, 2000, 2006, 2008, and 2009; spring trapnet assessments targeting black crappie in 1995 and 2006; spring electrofishing targeting largemouth bass in 1994, 2000, 2008 and 2009; fall electrofishing targeting juvenile walleye in 2001, 2003, and 2005; and summer trapnet assessments in 2008 and 2009. No standard lake survey gillnets have been set in Cedar Lake since 2000 due to the possibility of excessive mortality of large northern pike on this relatively small lake. Figure 10 summarizes basic catch statistics of each major species in Cedar Lake over its surveyed history.

Northern pike are a primary management species for Cedar Lake. Unlike many other lakes in the state, Cedar supports a high-quality pike population characterized by high abundance quality-sized individuals. Pike in the 0.86 m to 0.96 m (34 to 38 inch) range have been regularly observed in DNR sampling since 1983, while fish exceeding 0.76 m (30 inches) have generally made up 10-20% of the spring trapnet catch (Figure 11). Gillnet catch rates remained within the interquartile range for Lake Class 23 from 1983 to 2000 (Figure 10). Spring trapnet catches showed remarkable stability varying

Table 3: Fish species captured during past fisheries surveys.
Thermal guilds were classified by Lyons et al. (2009) and environmental tolerances were categorized by Drake and Pereira (2002)

Common name	Species name	Trophic guild	Thermal guild	Environmental tolerance[a]	First sampled
Northern pike	*Esox lucius*	Predator	Cool	Neutral	1959
Black crappie	*Pomoxis nigromaculatus*	Predator	Cool-warm	Neutral	1959
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1959
Rock bass	*Ambloplites rupestris*	Predator	Cool-warm	Neutral	1959
Bowfin	*Amia calva*	Predator	Warm	Neutral	1983
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1959
Cisco	*Coregonus artedi*	Planktivore	Cold	Intolerant	1959
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Cool-warm	Neutral	1983
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	Tolerant	1959
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	1983
Bluntnose minnow	*Pimephales notatus*	Omnivore	Warm	Neutral	1988
Common Carp	*Cyprinus carpio*	Omnivore	Warm	Tolerant	1949
Tadpole madtom	*Noturus gyrinus*	Insectivore	Warm	Neutral	2008
Yellow bullhead	*Ameiurus natalis*	Omnivore	Warm	Neutral	1959
Brook stickleback	*Culaea inconstans*	Insectivore	Cool	Neutral	2008
Iowa darter	*Etheostoma exile*	Insectivore	Cool	Intolerant	1995
Pugnose shiner[a]	*Notropis anogenus*	Insectivore	Cool	Neutral	2008
Banded killifish	*Fundulus diaphanus*	Insectivore	Cool-warm	Intolerant	1988
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-warm	Neutral	1995
Blacknose shiner	*Notropis heterolepis*	Insectivore	Cool-warm	Intolerant	1988

Table 3, Continued

Common name	Species name	Trophic guild	Thermal guild	Environmental tolerance[a]	First sampled
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1959
Hybrid sunfish	*Lepomis spp.*	Insectivore	Warm	Neutral	1959
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1959
Common shiner	*Notropis cornutus*	Insectivore	Warm	Neutral	1983
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	Neutral	1983
Green sunfish	*Lepomis cyanellus*	Insectivore	Warm	Neutral	1983
Blackchin shiner	*Notropis heterodon*	Insectivore	Warm	Intolerant	1995
Least darter[a]	*Etheostoma microperca*	Insectivore	Warm	Intolerant	2008
Mimic shiner[b]	*Notropis volucellus*	Insectivore	Warm	Intolerant	1988
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1959
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	Neutral	1983

[a]State-listed species of greatest conservation need
[b]Correct species identification is questionable since these species were not sampled over two years of intense nearshore sampling in 2008-2010.

from 5.06/set to 5.36/set in the four assessments between 1995 and 2008. The 2009 spring trapnet catch rate was 3.83/set. Northern pike growth rates are usually within the normal range for both sexes, although older females (over age 3) have shown fast growth during some years. Females grow noticeably faster than males. The reduced harvest of northern pike due to the conservation regulation has likely helped maintain a quality northern pike fishery.

Walleye have been a primary management species since 2002 when stocking was re-instated. Walleye gillnet catches from 1983 to 2000 were quite low and representative of a remnant population (Figure 10). No recent gillnet data is available for walleye since gillnetting was terminated after 2000. Since the advent of a renewed stocking program, MDNR sampling combined with multiple reports of good walleye fishing from anglers appears to show that stocking has been and continues to be successful in producing a healthy walleye population. A total of 54 walleye were captured in spring trapnets in 2006 (Figure 12). This sample was dominated by fish in the 0.45-0.61 m (18-24 inch) range. Spring trapnetting in 2008 provided a sample of 40 walleye mostly in the 0.48-0.64 m (19-25 inch) range. In 2009, there were 67 walleye caught in spring trapnets with nearly 2/3 exceeding 0.53 m (21 inches) long (Figure 12). Spring electrofishing in 2008 resulted in a catch of 13 smaller walleye ranging from 0.23-0.36 m (9-14 inches) in length. Female walleye demonstrate fast growth while males grow at a normal rate. Fast growth rates are often characteristic of newly introduced populations.

Black crappie has consistently produced low catch rates in routine summer sampling (trapnets and gillnets) over the lake's history. Catches have not exceeded 0.33/set in the gillnets and the highest trapnet catch (1.75/set) occurred in 1983 (Figure 10). Concerns about the low crappie population were expressed by local residents in the 1990s prompting the MDNR to conduct a spring trapnet assessment for the species in 1995. The 1995 netting caught 18 crappies primarily in the 0.25-0.29 m (10-11.5 inch) range. A similar assessment was undertaken in 2006 which captured 34 crappies representing five year classes. Five year classes of crappie were also present in the spring ice-out netting targeting northern pike in 2008 where a total of 21 crappies were captured. Individuals exceeding 0.33 m (13 inches) were present in 2006 and 2008 spring trapnets. Large crappies were also observed during spring electrofishing in 2009 when 15 fish were netted ranging from 0.28 to 0.34 m (11 to 13.2 inches) in length. Recent information suggests an improving crappie population in terms of abundance, recruitment consistency, and size structure. Crappies exhibit fast growth. Summer trapnets continue to fail to effectively sample crappie as none were captured in this gear in 2008 or 2009.

Bluegill abundance has shown no specific trend throughout the lake's netting history (Figure 10). Summer trapnet catches remained above the lake class 23 interquartile range from 1983 to 1994, and were within the interquartile range in 1959, 2000, 2008 and 2009. Bluegills exceeding 0.18 m (7 inches) have never been common in Cedar Lake with most summer samples showing modal lengths in the 0.1 to 0.13 m (4 to 5 inch) range. More bluegills over 0.18 m have been observed in recent years, with four individuals in excess of 0.2 m (8 inches) measured in the 2009 summer trapnets. This is first evidence of bluegill over 0.2 m in the DNR sampling record. Bluegill grow slowly in Cedar Lake, and thus large individuals are vulnerable to overharvest.

Largemouth bass have a history of high abundance in Cedar Lake. Spring electrofishing catch rates have consistently been the highest recorded in the Little Falls work area. Although largemouth bass are not highly vulnerable to trapnets and gillnets, historical gillnet data also shows high abundance with catches above the lake class 23 interquartile range dating back to 1959. Largemouth bass populations have more recently been targeted using electrofishing. The 2009 spring electrofishing catch rate was extremely high at 344 fish per hour. Since 2008, bass have been sampled using a new electrofishing boat which has proven more effective in capturing bass (and thus at same population levels produce higher catch rates than the old electrofisher). Thus 1994/2000 and 2008/2009 survey years are not comparable in terms of catch per effort. Nevertheless, bass populations in Cedar Lake have been dominated by small fish and fish size appears to have declined over time with mean lengths of 0.31 m (12.1 inches) in 1994, 0.26 m (10.24 inches) in 2000, 0.25 m (9.98 inches) in 2008 and 0.23 m (9.24 inches) in 2009. As far as the presence of larger bass (>0.38 m), we captured 9 in 1994, 7 in 2000, 8 in 2008 and 2 in 2009.

Although size-structure of largemouth bass appears skewed toward smaller individuals, this may be a natural phenomenon since the good habitat quality and abundant minnows in Cedar Lake should support high recruitment of largemouth bass. The lack of significant numbers of large individuals in the population needs to be investigated. Evaluating population age-structure, angler harvest and availability of larger prey to support adult growth are three factors that should help shed light on mechanisms regulating the largemouth bass population in Cedar Lake.

Yellow perch numbers have been low in Cedar Lake since the initial netting in 1959. The highest recorded gillnet catch was 1.66/set noted in 1983. No perch were captured in gillnets in 1994 or 2000. Small numbers of perch continue to be observed during spring and summer trapnetting and electrofishing. Seining and electrofishing performed during IBI surveys has also shown some perch recruitment.

Yellow bullheads are the predominant ictalurid (catfish) species in Cedar Lake. Historical gillnet data indicates their abundance often falls within the interquartile range for Lake Class 23. Yellow bullheads are expected to be the most common of the three bullhead species in clear lakes with good water quality. Brown bullheads have also been documented in Cedar Lake and are common in northern Minnesota Lakes. Black bullhead are present in the lake but at a low abundances. It will be important to monitor changes in black bullhead relative abundance as increases in their populations are often indicative of declining water quality conditions.

Cisco (tullibee) are found in small sizes in Cedar Lake; a cold-water species that requires well-oxygenated deep water for its persistence. Consequently, Minnesota populations are threatened by climate change (Jacobson et al. 2008). Cisco provide a valuable prey source for northern pike and walleye in Cedar Lake as well as hundreds of other northern Minnesota lakes.

Gillnet catches have generally been quite low with the exception of 2000 when the catch was 15.2/set in one net (Figure 10). This high catch may not have been indicative of a population spike, but rather a netting anomaly, and indicative of a population that's patchily distributed during summer. Cisco have been observed in the stomachs of many predator fish during past gillnet surveys even when gillnet catches showed few if any ciscos present. It is believed that summer gillnetting does not accurately depict cisco abundance in Cedar Lake. Additional efforts to sample cisco were made in the summer of 2009 and 2010 using suspended gillnets, vertical gillnets and hydroacoustics; however, no cisco were sampled in the suspended gillnets or the vertical gillnets. Targeted sampling during fall when cisco disperse for spawning may be needed to ascertain their population status in Cedar Lake. Given their importance to lake food webs and sensitivity to climate change, graduate research by the University of Minnesota Duluth (Lead: Dr. Tom Hrabik) will explore alternative hydroacoustic and netting methods in Cedar Lake to understand population dynamics and habitat use of these species.

Cedar Lake is a deep lake that strongly stratifies (Figure 13). Oxygen concentrations usually remain sufficient in the metalimnion and into the hypolimnion during the period of greatest oxythermal stress (July 28 through August 27 for stratified lakes). Pronounced metalimnetic oxygen maxima occurred in 1994 and 2000. Metalimnetic oxygen maxima occur when photic depth exceeds thermocline depth and photosynthesis allows oxygen concentrations to remain high in the cool waters of the metalimnion. Metalimnetic oxygen maxima are usually associated with lakes with good water quality (high Secchi depths).

The benchmark measure of coldwater habitat (temperature at 3 mg O_2 (TDO_3); Jacobson et al. (2010) suggest that coldwater resources in Cedar are excellent (Table 4). The mean TDO_3 was 10.3°C during the period of greatest oxythermal stress. On a scale of 0 to 100 (with 0 being worst and 100 best), Cedar Lake has a Cisco Habitat Suitability Index of 98. Profile data re-plotted as temperature vs. oxygen (Figure 13) illustrate how close oxythermal habitat approached lethal conditions (Jacobson et al. 2008). All profiles contained conditions where cisco could survive and were well away from the lethal niche boundary. Maintaining the good water quality that exists in Cedar Lake will be critical for maintaining suitable habitat for cisco.

Table 4: Temperatures at 3 mg O_2 from Cedar Lake. Interpolated from the profiles taken by MPCA and MDNR during the period of greatest oxythermal stress (July 28 through August 27, 2009).

Date	TDO_3
8/1/1994	10.2
7/31/2000	7.7
8/25/2006	13.4
7/29/2008	7.5
8/12/2008	7.9
8/25/2008	7.9
8/12/2009	13
8/22/2009	14.6
Mean	10.3

Figure 10: Catch per effort (numbers per net; GN = gillnet, TN = trapnet) of the major species in Cedar Lake recorded during historical fisheries surveys.

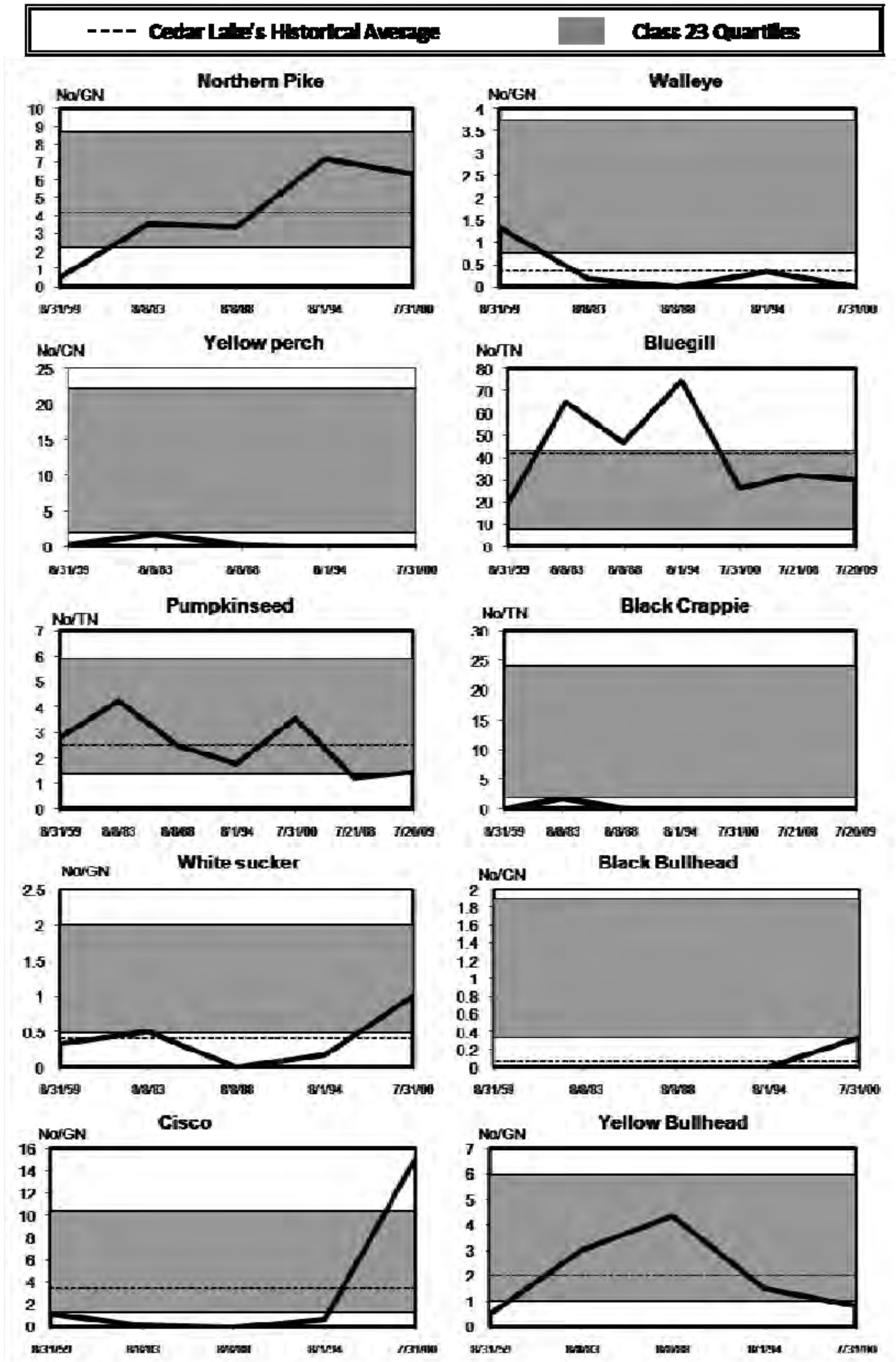


Figure 11: Percent northern pike greater than 0.76 meters captured in trapnets set during ice-out in Cedar Lake.

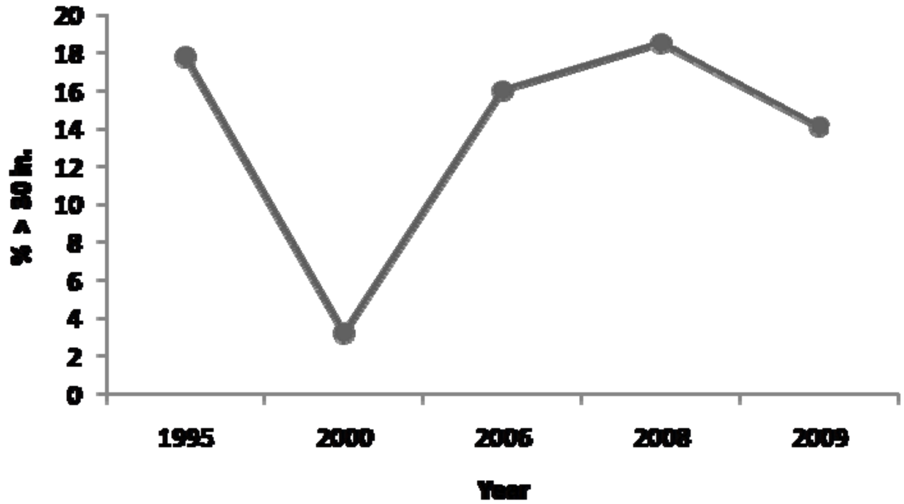


Figure 12: Percent walleye greater than 0.46 meters captured in trapnets set during ice-out in Cedar Lake.

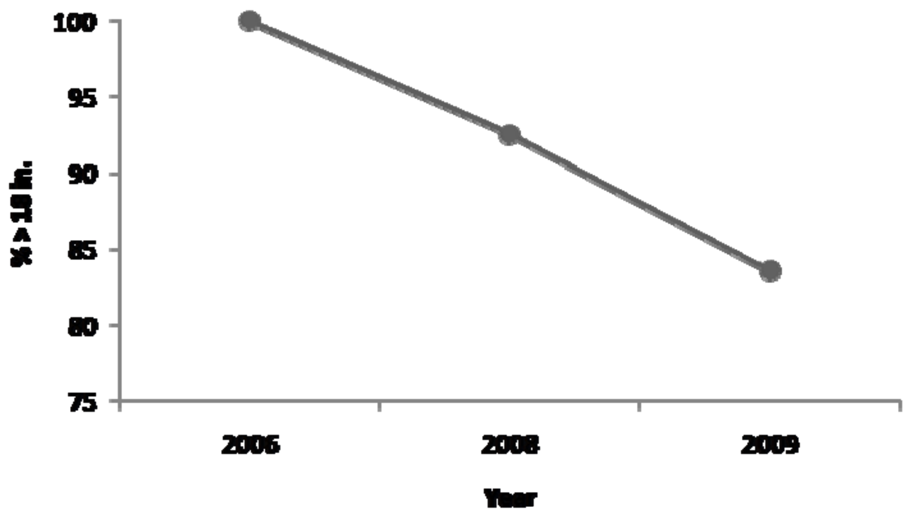
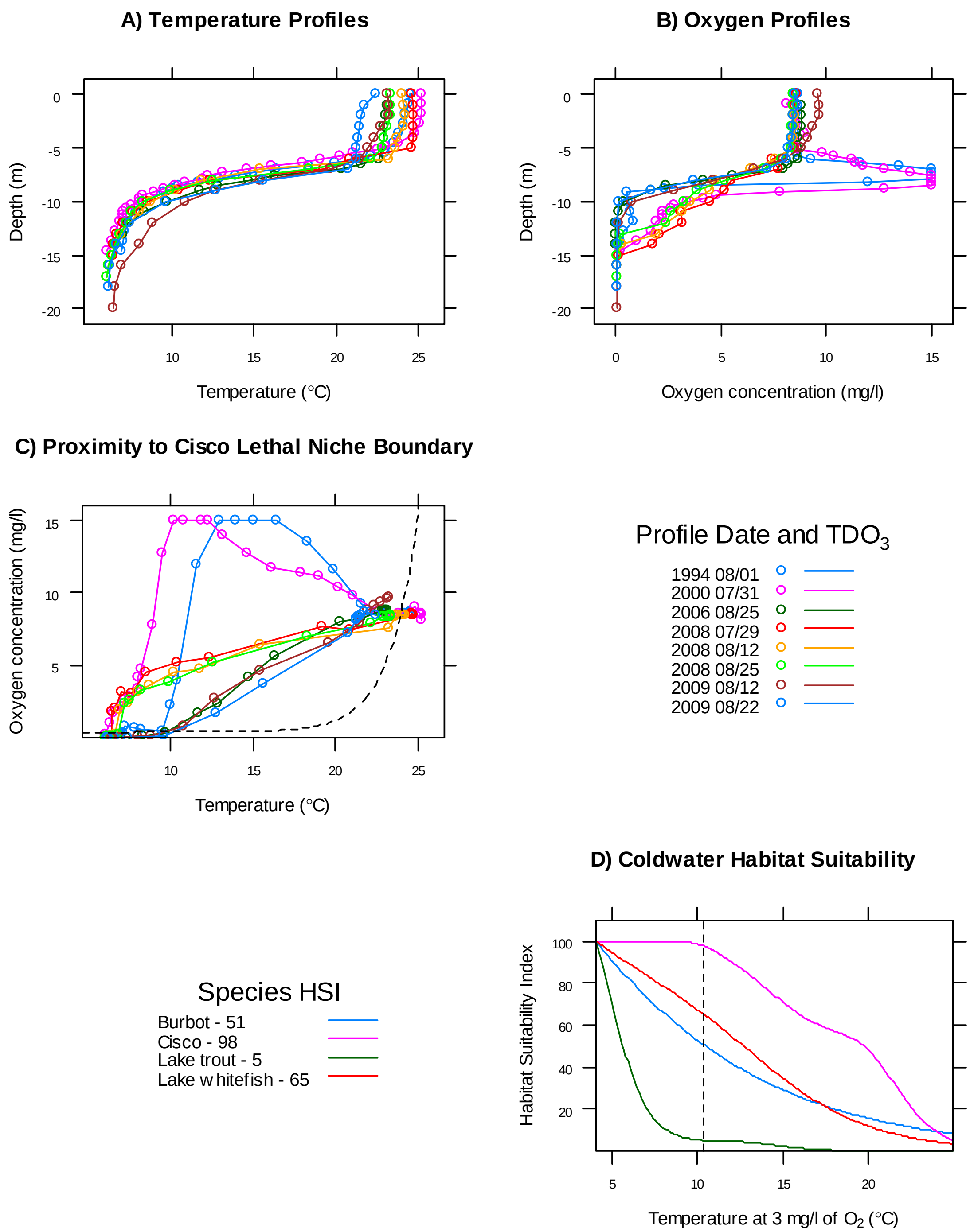


Figure 13: Cisco oxythermal habitat in Cedar Lake. A) and B) are MDNR and MPCA profiles taken during the period of greatest oxythermal stress (July 28 through August 27). C) is the profile data re-plotted for comparison with lethal oxythermal conditions for cisco (dashed line). The dashed line in D) represents coldwater habitat suitability in relation to the entire gradient of HSIs in Minnesota.



Aquatic Plant Assessment

Emergent and floating leaf vegetation occurs along approximately 47% of Cedar Lake's shoreline and covers a total of 6.3 ha (15.5 acres). Cattails (*Typha* spp.) and hardstem bulrush (*Scirpus acutus*) are widespread and account for 4 ha (10 acres) of emergent and floating leaf cover (Figure 14) and according to 2005 estimates, cover approximately 6.3 ha of the littoral zone. At modest to high levels of abundance or biovolume, aquatic vegetation covered approximately 44% of the lake's surface area or 43 ha (107 acres) in 2008 (Figure 15). Vegetation was most variable but overall, most abundant at shallow depths (Figure 16). This "boot-like" statistical distribution of biovolume as a function of depth is common in mesotrophic lakes (Valley and Drake 2007). Overall, vegetation occupied approximately 27% of the water column, but Figure 15 clearly demonstrates that vegetation growth was patchy across different areas of the lake. Vegetation grew along most bottom areas up to 7.6 m (25 feet).

The submersed community is relatively diverse (Tables 5 and 6; Figure 17) with 13 species occurring greater than or equal to 10% in less than 4.6 m of water in 2009. Still, the plant community is dominated by low-growing, muskgrass or *Chara* sp. This species, among several others have been common across the history of aquatic plant surveys in the lake (Table 6). Species frequencies changed little from 2008 and 2009. Additional surveys in Cedar in 2010 and 2011 compared across repeated surveys in all sentinel lakes will help researchers determine how much aquatic plants naturally vary from year to year and to separate natural 'noise' from a disturbance signal.

Curly-leaf pondweed (*Potamogeton crispus*) was first documented in Cedar Lake was in 2005, detected during reconnaissance surveys for the plant. However, it's speculated the plant has been present for some time occurring at very low levels of abundance. Curly-leaf pondweed is a non-native invasive submerged aquatic plant that is widespread throughout the southern part of the state. The exact date of introduction into Minnesota is unknown, but it is believed to have been present in Minnesota lakes since the early 1900's when carp were brought into the state. Curly-leaf pondweed grows most abundantly during early spring and senesces by mid-summer. When curly-leaf pondweed is abundant, mid-summer diebacks often promote algae blooms which limit light penetration for native aquatic plants.

Curly-leaf pondweed thrives in nutrient-rich conditions and at some threshold of nutrient levels (exact quantity unknown), may become a self-sustaining internal driver of poor water quality conditions. These self-perpetuating conditions of curly-leaf booms followed by large summer die-offs and algae blooms are most common in eutrophic to hypereutrophic lakes in the southern half of the state.

In northern mesotrophic lakes with abundant native aquatic plants, curly-leaf pondweed is less abundant and typically is integrated with other aquatic plants. Because the plant needs to photosynthesize during winter, curly-leaf pondweed is sensitive to long periods of snow and ice cover on lakes. Reduced snow and ice cover due to climate change may favor increases in this plants abundance in infested lakes and latitudinal range of viability. Spring surveys in 2008 and 2009 indicated that curly-leaf pondweed was present in Cedar but occurred at abundances that were not detected by standard sampling.

In 2009, muskgrass was the most common species sampled in Cedar Lake (Table 5). Muskgrass is a benthic plant that is highly desirable from a fish habitat and water quality standpoint. Besides offering quality physical habitat for small fish, muskgrass is an important plant for maintaining clear water. In turn, clear water promotes muskgrass (Kufel and Kufel 2002; Ibelings et al. 2007). To best prevent a shift to a curly-leaf pondweed regime and protect fish habitat, muskgrass beds should be protected along with reductions to external phosphorus loading.

Figure 14: Major emergent beds mapped with GPS in summer 2009.

Figure 15: Percent of water column occupied by submersed vegetation (biovolume) in Cedar Lake in June 2008. Assessed using hydroacoustics and interpolation of point estimates of biovolume with local kriging (Valley et al. 2005).

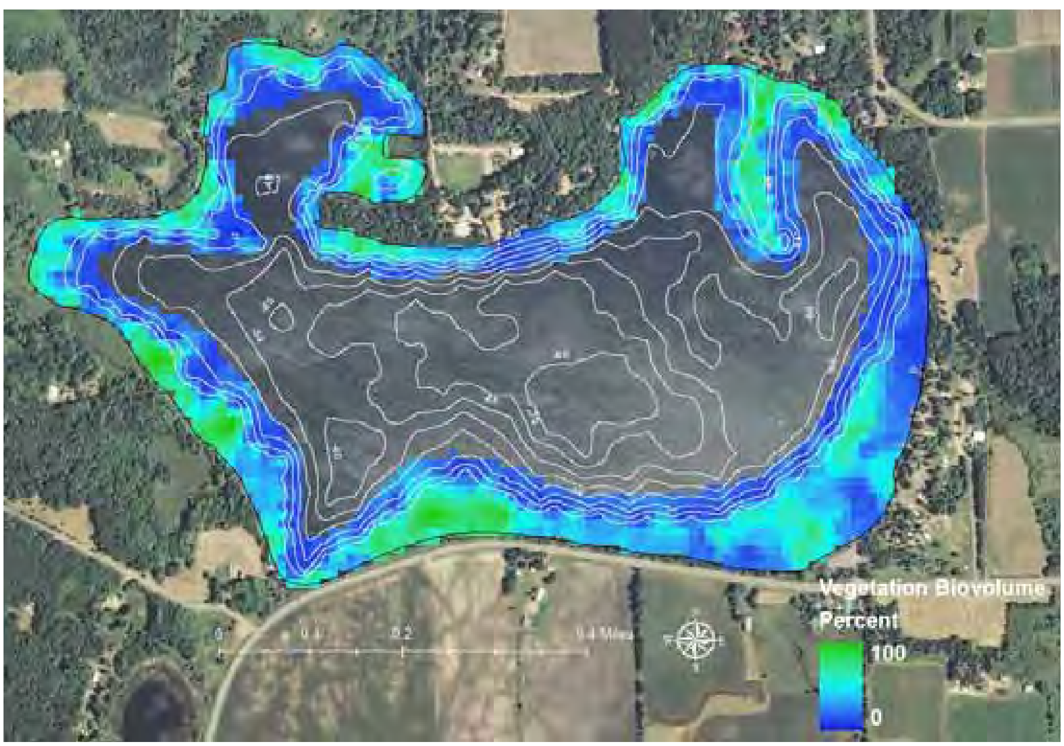


Figure 16: Vegetation biovolume as function of depth in Cedar Lake August 2008. A regression smoother shows the general trend of the data.

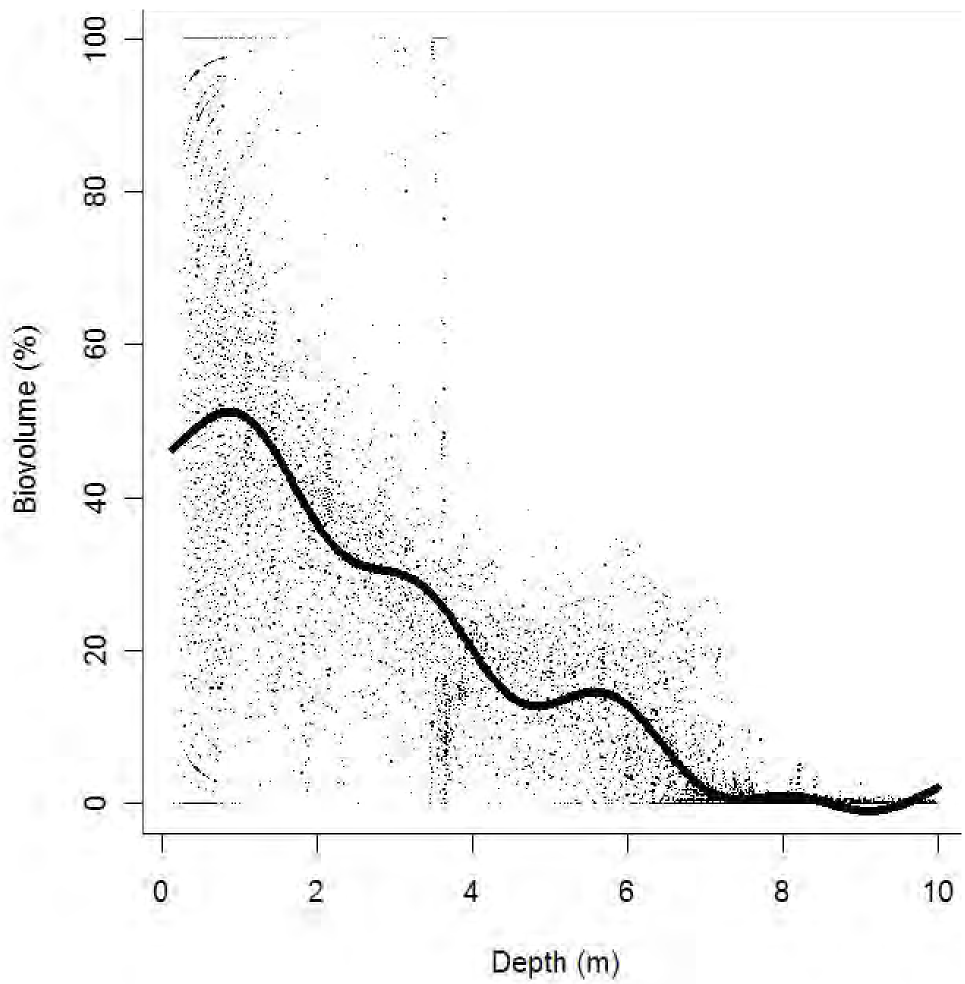


Figure 17: Number of aquatic plant species sampled per survey point during aquatic plant surveys in July 2009.

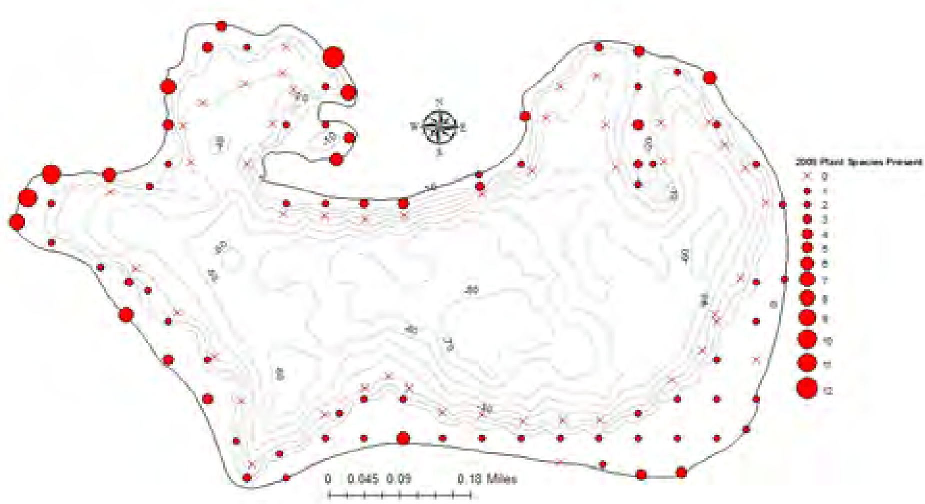


Table 5: Percent frequency of occurrence of aquatic plant species at depths ≤ 4.6 m sampled during point-intercept surveys on Cedar Lake, Morrison County, MN, 21 July 2008 and 20 July 2009.

Season	Common Name	Species Name	Growth Form	Frequency (%) 2008	2009
Spring[a]	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	0 [c]	0 [d]
Summer	All rooted plants			94.7	97.2
	Muskgrass	*Chara sp.*	Submersed	78.9	80.6
	Sago pondweed	*Stuckenia pectinata*	Submersed	35.1	19.4
	Filamentous algae			29.8	36.1
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	21.1	18.1
	Illinois pondweed	*Potamogeton illinoensis*	Submersed	19.3	18.1
	Coontail	*Ceratophyllum demersum*	Submersed	17.5	20.8
	Bushy pondweed	*Najas flexilis*	Submersed	14.0	15.3
	Large-leaf pondweed	*Potamogeton amplifolius*	Submersed	12.3	2.7
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed	12.3	12.5
	Wild Rice	*Zizania palustris*	Emergent	12.3	13.9
	Cattail group	*Typha sp.*	Emergent	10.5	9.7
	Yellow waterlily group	*Nuphar sp.*	Floating	10.5	9.7
	White waterlily group	*Nymphaea sp.*	Floating	10.5	12.5
	Hardstem Bulrush	*Scirpus acutus*	Emergent	7.0	6.9
	Fries pondweed	*Potamogeton friesii*	Submersed	7.0	9.7
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	5.3	2.8
	Greater duckweed	*Spirodela polyrhiza*	Free Floating	5.3	2.8
	Arrowhead group	*Sagittaria sp.*	Emergent	5.3	5.5
	Lesser duckweed	*Lemna minor*	Free Floating	5.3	8.3
	White water buttercup Group	*Ranunculus sp.*	Submersed	5.3	0
	Bladderwort	*Utricularia sp.*	Submersed	3.5	5.6
	Star duckweed	*Lemna trisulca*	Submersed	3.5	8.3
	Naiad group	*Najas sp.*	Submersed	3.5	
	Floating-leaf pondweed	*Potamogeton natans*	Submersed	3.5	9.7
	Narrow-leaf pondweed Group	*Potamogeton sp.*	Submersed	3.5	1.4
	White-stem pondweed	*Potamogeton praelongus*	Submersed	1.8	1.4
	Needlerush	*Eleocharis acicularis*	Emergent	1.8	1.4
	Water star-grass	*Heteranthera dubia*	Submersed	1.8	1.4
	Emergent burreed group	*Sparganinm sp.*	Emergent	1.8	1.4
	Canada waterweed	*Elodea canadensis*	Submersed	0	1.4
	Spikerush Group	*Eleocharis sp.*	Emergent	0	2.8
	Burreed Group	*Sparganinm sp.*	Emergent	0	1.4

[a] Spring surveys target curly-leaf pondweed
[b]Non-native
[c]curly-leaf not sampled but observed 2008
[d] 3 June 2009

Table 6: Common species observed during previous transect surveys. Species documented were either labeled as "common" at any transect or found at ≥ 10% of the transects

Date	Common Name	Species Name	Growth Form
8/11/1983	Hardstem bulrush	*Scirpus acutus*	Emergent
	Arrowhead	*Sagittaria sp.*	Emergent
	Yellow waterlily	*Nuphar variegatum*	Floating leaf
	Floating-leaf pondweed	*Potamogeton natans*	Floating leaf
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed
	Variable-leaf pondweed	*Potamogeton gramineus*	Submersed
	Large-leaf pondweed	*Potamogeton amplifolius*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Narrow-leaf pondweed	*Potamogeton spp.*	Submersed
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
	Lesser duckweed	*Lemna minor*	Free floating
8/01/1994	Hardstem bulrush	*Scirpus acutus*	Emergent
	Cattail	*Typha sp.*	Emergent
	Arrowhead	*Sagittaria sp.*	Emergent
	Wild Rice	*Zizania aquatica*	Emergent
	Yellow waterlily	*Nuphar variegatum*	Floating leaf
	White waterlily	*Nymphaea odorata*	Floating leaf
	Variable-leaf pondweed	*Potamogeton gramineus*	Submersed
	Bladderwort	*Utricularia sp.*	Submersed
	Large-leaf pondweed	*Potamogeton amplifolius*	Submersed
	Canada waterweed	*Elodea canadensis*	Submersed
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
	Mud plantain	*Zosteralla dubia*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
	Whitestem pondweed	*Potamogeton praelongus*	Submersed
	Filamentous algae		
	Lesser duckweed	*Lemna minor*	Free floating
7/24/2006	Hardstem bulrush	*Scirpus acutus*	Emergent
	Cattail	*Typha sp.*	Emergent
	Arrowhead	*Sagittaria sp.*	Emergent
	Wild Rice	*Zizania aquatica*	Emergent
	Green-fruited burred	*Sparganium*	
	Yellow waterlily	*Nuphar variegatum*	Floating leaf
	White waterlily	*Nymphaea odorata*	Floating leaf
	Floating-leaf pondweed	*Potamogeton natans*	Floating leaf
	Variable-leaf pondweed	*Potamogeton gramineus*	Submersed

Table 6: Continued

Date	Common Name	Species Name	Growth Form
	Illinois pondweed	*Potamogeton illinoinensis*	Submersed
	Bladderwort	*Utricularia sp.*	Submersed
	Large-leaf pondweed	*Potamogeton amplifolius*	Submersed
	Canada waterweed	*Elodea canadensis*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
	Water buttercup	*Ranunculus sp.*	Submersed
	Mud plantain	*Zosteralla dubia*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Fries' pondweed	*Potamogeton friesii*	Submersed
	Whitestem pondweed	*Potamogeton praelongus*	Submersed
	Filamentous algae		
	Greater duckweed	*Spirodela polyrrhiza*	Free floating
	Star duckweed	*Lemna trisulca*	Free floating
	Lesser duckweed	*Lemna minor*	Free floating

Water Quality

Standard summer-mean water quality data for 2008-2010 are presented in Table 7, and raw data results are provided in Appendix B. In addition, major cations, anions, and total organic carbon were analyzed on three sample dates, and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 8. The NLA was a statistically-based survey of the nations lakes administered by the United States Environmental Protection Agency in 2007. The typical range provided in Table 8 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Table 7: Cedar Lake 2008-2010 summer mean (June to September) water quality
Typical range based on 35 NCHF ecoregion reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	Cedar Lake	NCHF
Total phosphorus (µg/L)	13	23 - 50
Chlorophyll mean (µg/L)	2.9	5 - 22
Chlorophyll max (µg/L)	5.2	7 - 37
Secchi disk (feet) (meters)	14.1 4.3	4.9 – 10.5 1.5 – 3.2
Total Kjeldahl Nitrogen (mg/L)	0.6	<0.6 – 1.2
Alkalinity (mg/L)	155	75 - 150
Color (Pt-Co Units)	7	10 - 20
pH (SU)		8.6 – 8.8
Chloride (mg/L)	6.2	4 - 10
Total suspended solids (mg/L)	2.1	2 - 6
Total suspended inorganic solids (mg/L)	0.3	1 - 2
Conductivity (µmhos/cm)		300 - 400
Total nitrogen : Total phosphorus ratio	46:1	25:1 - 35:1

Table 8: Cedar Lake cation, anion, and total organic carbon measurements

Date	Ca[1] mg/L	Mg mg/L	Na mg/L	K mg/L	Alk mg/L	SO_4 mg/L	Cl mg/L	TOC mg/L
5/6/2008	36.8	19.7	4.9	2.5	170	8.7	5.9	6.0
7/15/2008	28.8	20.6	5.6	2.2	150	8.8	5.9	6.5
10/7/2008	28.8	20.4	5.9	2.3	150	8.4	5.8	6.7
5/28/2009	37.5	20.5	5.4	2.3	170	8.3	6.2	6.7
7/29/2009	30.3	20.6	5.4	2.2	150	8.3	5.8	6.6
10/5/2009	30.7	20.2	5.4	2.3	160	8.5	6.3	6.3
5/20/2010	43.0	23.1	6.4	2.8	170	8.3	6.4	6.1
7/27/2010	28.3	20.1	5.2	2.1	150	7.9	6.3	5.8
10/20/2010	27.9	16.8	4.9	1.9	160	7.6	6.3	6.2
Average	32.5	20.2	5.4	2.3	160	8.3	6.1	6.3
µeq/L	1622	1662	235	59	3200	173	172	
NLA IQ range (mg/L)	19.1 – 33.7	6.7 – 26.9	2.2 – 9.0	0.9 – 4.8		2.2 – 14.0	1.5 – 18.4	7.3 – 14.2

NLA typical range provided as a basis for comparison. [1]Microequivalents (µeq/L) based on average value. Ion concentrations expressed as element (e.g. Ca as Ca)

Dissolved Oxygen and temperature profiles were taken a minimum of twice per month at site 202 (Figures 18 and 19). Stratification begins in mid- to late-May and is sustained through September and into early October (Figure 19). Surface temperatures peaked at 29°C in August 2010; a week and a half prior, the maximum temp had been 26°C. Below a depth of approximately 6-10 meters during the mid-summer months, DO dropped below 5 mg/L (milligrams per liter) and temperature declined to a minimum of 5°C. Metalimnetic DO maxima were observed in June of 2009 and 2010; these were also noted in the earlier sampling in the mid-80s. Metalimnetic maximum DO is common in clear mesotrophic lakes and is a function of algal productivity in this layer and cool water that holds more oxygen (as compared to warmer water in the epilimnion).

Total phosphorus (TP) concentrations in Cedar Lake averaged 13 µg/L (Table 7). This is well below the typical range for reference lakes in the NCHF ecoregion. The highest observed value (34 µg/L; Figure 20) was taken shortly after ice out (Figure 19) under well-mixed conditions (Figure 19). Generally, values were between 10 and 16 µg/L with the highest concentrations typically observed in the spring. The pattern of stable to slightly declining TP from June through September is consistent with other dimictic lakes. Cedar Lake remained stratified into October and thus “fall” samples did not reflect well-mixed conditions in 2008 and 2009. Hypolimnetic TP values ranged from a low of 22 µg/L to a high of 173 µg/L (Figure 22). In 2008, hypolimnetic TP remained relatively low, never exceeding 54 µg/L; the following years values were well into the 100s during stratified conditions. October samples in 2008 and 2009 reaffirm that fall mixing had not occurred as of those sample dates; however similar epi- and hypolimnetic TP in October 20, 2010 suggests that mixing had occurred as of that sample date. The October 2010 data also suggest that while TP is high in the hypolimnion the volume of the hypolimnion is small relative to the epilimnion and only a minor increase in epilimnetic TP is observed.

Nitrogen, measured as total Kjeldahl nitrogen (TKN), a primary nutrient required for algal and plant growth was on the low end of the typical range for NCHF lakes (Table 7). Nitrate-N, which is readily used by algae and rooted plants was at or below detection on most sample dates (Appendix). The TN:TP ratio is higher than the typical range (Table 7) and indicates Cedar Lake is strongly P-limited.

Chlorophyll-*a* (chl-*a*) concentrations provide an estimate of the amount of algal production in a lake. Chl-*a* concentrations averaged 2.9 µg/L, over the summers of 2008-2010 (Figure 20). This is below the typical range for NCHF reference lakes (Table 6). Chl-*a* concentrations tend to increase across the season, as the waters warm; however, the values usually in Cedar were less than 5 ug/L and noticeable surface accumulations of algae were typically not observed.

Secchi disk transparency averaged 4.3 meters (14 feet) over 2008-2010. This is above (better than) the typical range of NCHF reference lakes. Transparency corresponded well to TP and chl-*a* concentrations; increases in those parameters resulting in a decline in transparency (Figure 20).

Figure 18: Cedar Lake 2008-2010 dissolved oxygen

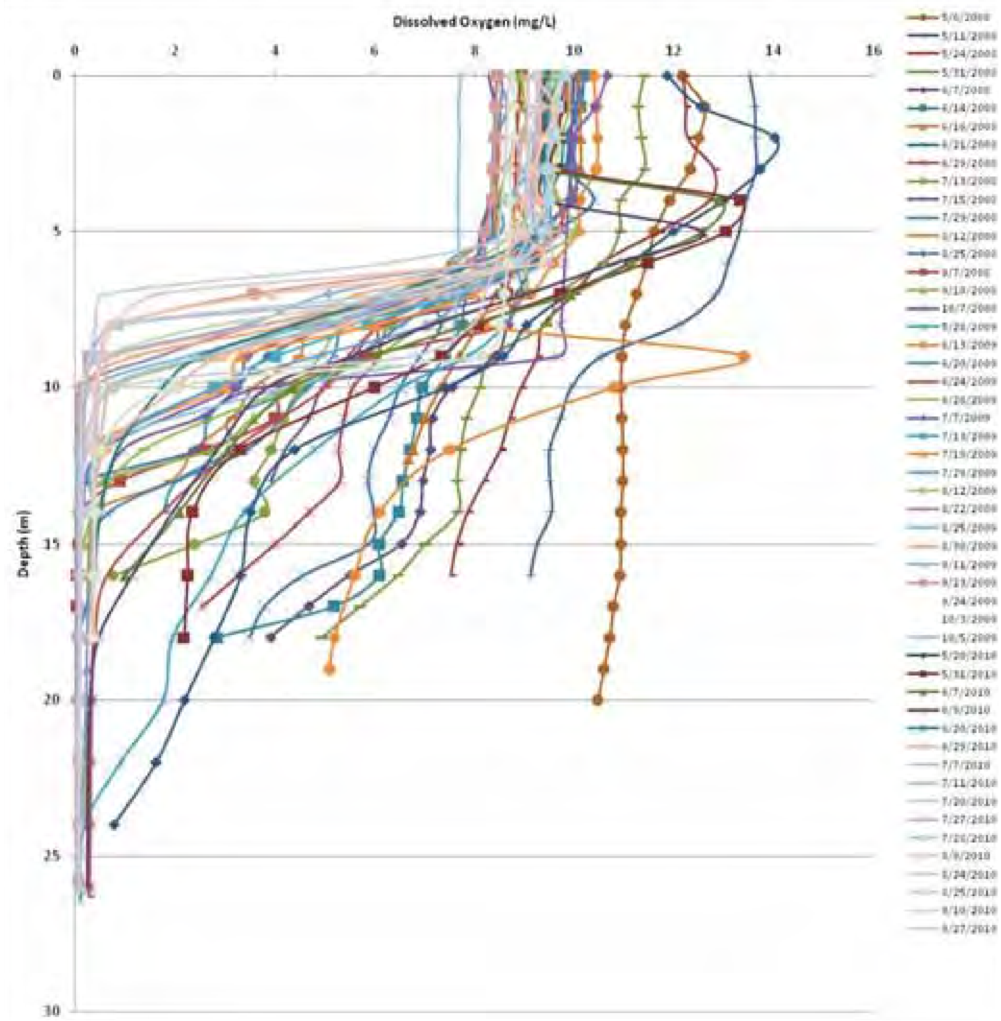


Figure 19: Cedar Lake 2008-2010 temperature

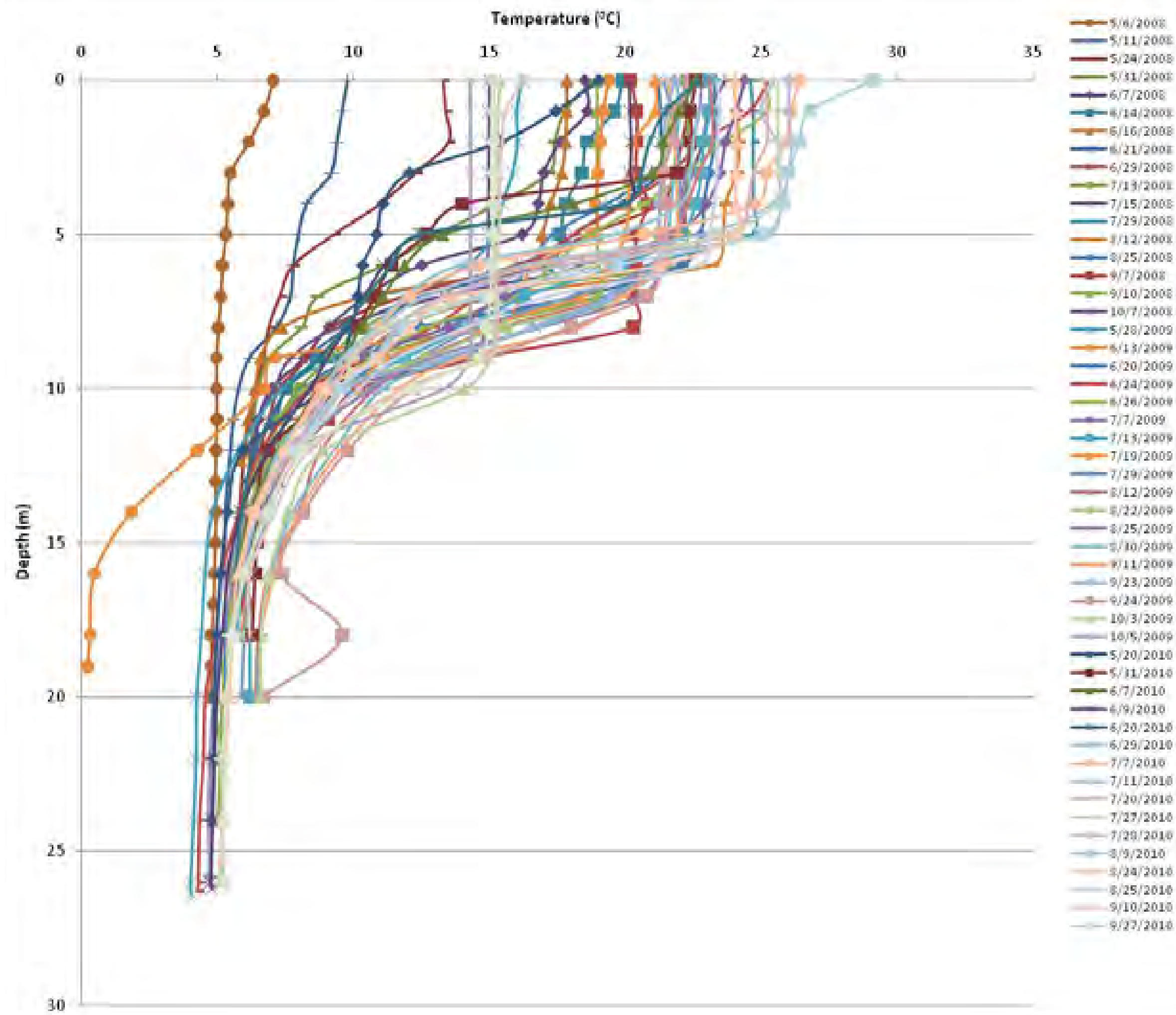


Figure 20: Cedar Lake 2008-2010 paired total phosphorus, chlorophyll-*a* concentrations, & Secchi depth

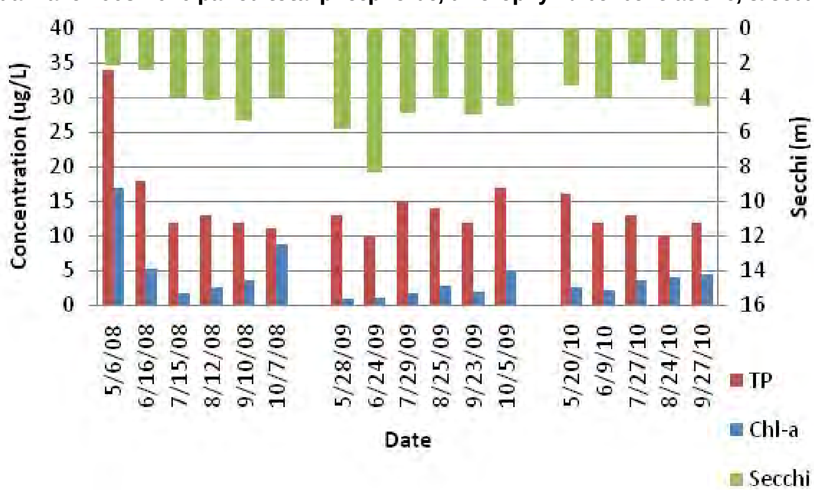
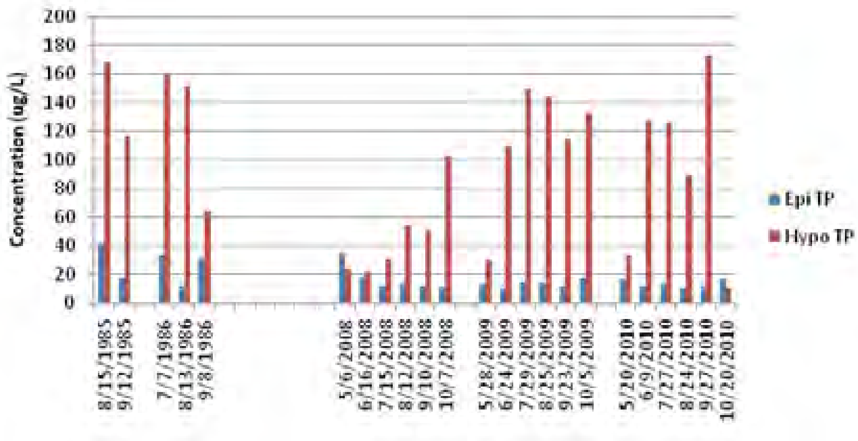


Figure 21: Cedar Lake paired hypolimnetic and epilimnetic total phosphorus observations



Dissolved minerals and organic carbon were measured as part of the long-term monitoring of Cedar and other Sentinel lakes. This includes some of the standard measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 7) as well as major cations, anions, and organic carbon (Table 8). While several of these parameters have "typical" ecoregion-based concentrations (e.g. Table 7); some do not. For parameters without ecoregion–based comparisons, data from the 2007 National Lakes Assessment (NLA) study were used to provide perspective on reported concentrations (Table 8). Since the NLA lakes were selected randomly they provide a reasonable basis for describing typical ranges and distributions at the state-wide level (Heiskary and Lindon 2010).

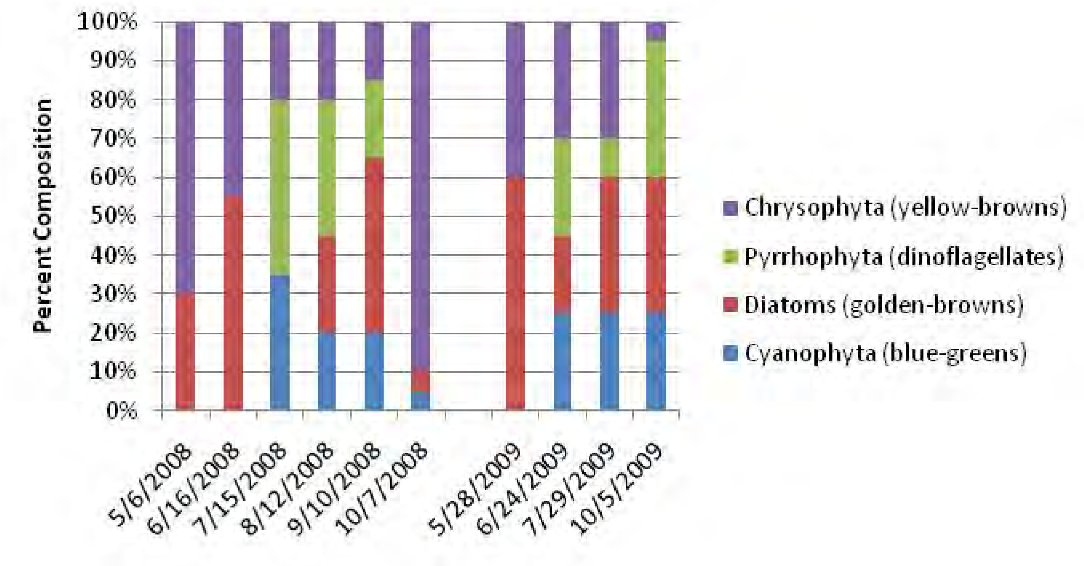
TSS is quite low and consistent with the typical range for NCHF reference lakes (Table 7) and most of the TSS can be attributed organic solids (decomposing algal matter). The low color value (Table 7) indicates the water is clear and has minimal amount of total organic carbon (TOC) (Table 8). Lakes that receive a majority of their water inputs from forest and wetland runoff often have correspondingly higher color and TOC values as a result of incompletely dissolved organic matter (plants, leaves, and other organic material).

Alkalinity and conductivity are in the typical range for NCHF lakes, with alkalinity on the high end of the range and conductivity on the low end (Table 7). Calcium (Ca) and magnesium (Mg) are the dominant cations (based on µeq/L) and both are within the typical range of the state-wide data (Table 8). The other two major cations – sodium (Na) and potassium (K) are within the typical range as well. Bicarbonate (alkalinity expressed as $CaCO_3$) is the dominant anion, followed by sulfate (SO_4) and chloride (Cl). Chloride is within the typical range for NCHF reference lakes (Table 7). Elevated Cl is most often attributed to application of salt on roads in the watershed, though leaching from septic systems is a potential source as well.

Most cation and anion concentrations, with the exception of Ca, were quite stable across sample events in 2008-2010 (Table 8), which is consistent with the literature. Mg, Na, K and Cl are noted to be relatively conservative and undergo only minor spatial and temporal change (Wetzel 2001). Mg is required by algae to produce chl-*a*. Rooted plant uptake of Ca is a likely reason for the mid-summer decline in Ca (Table 8).

Phytoplankton (algae) composition varied throughout the summer. Typically a transition from diatoms dominating the composition in the spring to blue-greens in the summer occurs. Diatoms and yellow-browns were the most common forms in May and June (Figure 22). Dinoflagellates were prominent in July 2008 and June 2009 samples and were present throughout the summer (Figure 22). It should be noted that algal biomass, as reflected by chl-*a*, was quite low and the water was clear throughout most of the summer. Blue-green algae were never dominant and no blooms were recorded in 2008 to 2010 monitoring.

Figure 22: Algal composition for Cedar Lake in 2008 and 2009



Zooplankton

Zooplankton samples were analyzed by Jodie Hirsch at the MDNR. A summary report was prepared that included information for all the Sentinel lakes sampled in 2008 (Hirsch 2009). Results from 2009 and 2010 were charted by MPCA staff and will be included in the discussion below (Appendix C).

Cedar Lake had one of the lowest number of taxa (11) observed in the 2008 season and the lowest mean density and biomass of the lakes in the NCHF ecoregion (Table 9). The June sample had the highest density and July had the highest biomass across 2008. Hirsch (2009) found that, in general, as lake productivity increased (e.g. TP or chl-*a*) the relative abundance and biomass of zooplankton increased as well. This appears to be the case for Cedar and the other NCHF lakes (Figure 22).

Table 9: Mean annual zooplankton densities, biomass, and total number of taxa for each Sentinel lake

Sentinel Lakes Zooplankton 2008	Mean Annual Densities (#/L)	Mean Annual Biomass (µg/L)	Total# Taxa
Western Corn Belt Plains			
Artichoke	139.64	724.05	12
Shaokotan	107.55	1070.97	11
St. James	62.73	108.56	10
St. Olaf	60.23	336.20	15
Carrie	56.41	254.21	13
Madison	52.78	310.93	14
North Central Hardwood Forest			
Peltier	78.75	1098.39	12
Pearl	59.68	221.13	14
Belle	57.67	340.06	12
South Center	24.72	123.71	18
Carlos	19.66	73.49	16
Cedar	11.31	41.85	11

Table 9: Continued

Sentinel Lakes Zooplankton 2008	Mean Annual Densities (#/L)	Mean Annual Biomass (µg/L)	Total# Taxa
Northern Lakes and Forests			
Portage Lake	100.10	277.38	10
Cedar	79.31	127.96	18
South Twin	25.83	54.93	12
Hill	17.73	147.29	11
Elk	16.95	47.10	12
Ten Mile	14.94	44.89	14
Border Lakes (NLF)			
Echo	37.03	89.68	12
Elephant	13.26	75.50	12
White Iron	10.00	38.64	14
Trout	6.28	29.52	13
Bearhead	5.15	38.37	14
Northern Light	1.03	4.16	13

Figure 23: Mean monthly zooplankton densities and biomass for North Central Hardwood Forest Ecoregion Sentinel lakes in 2008

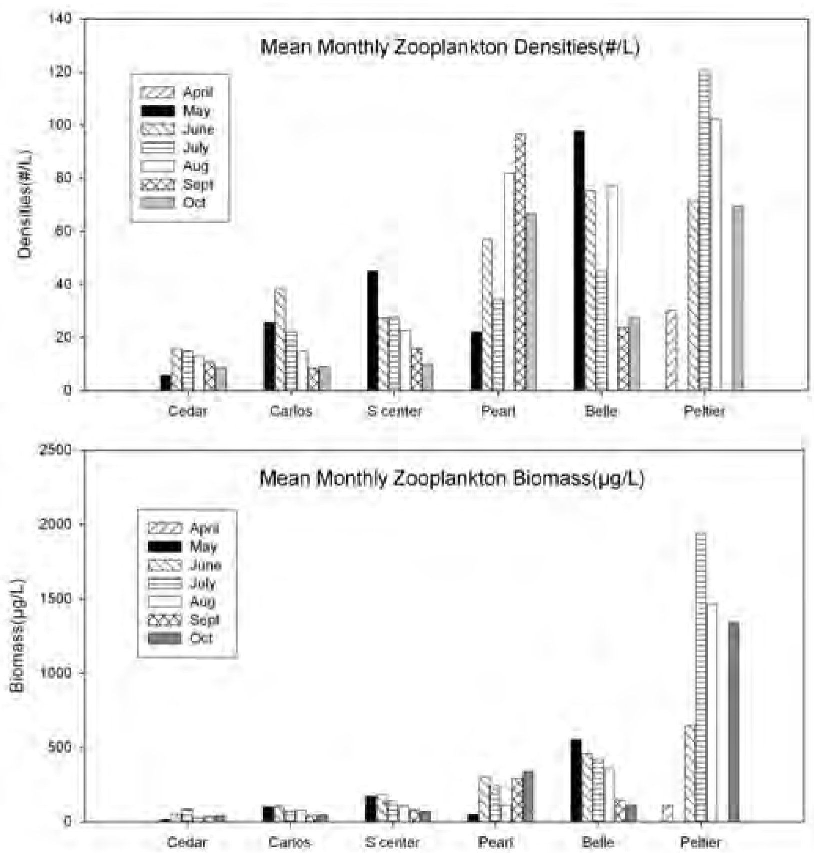


Figure 24. Mean monthly zooplankton density (#/L)

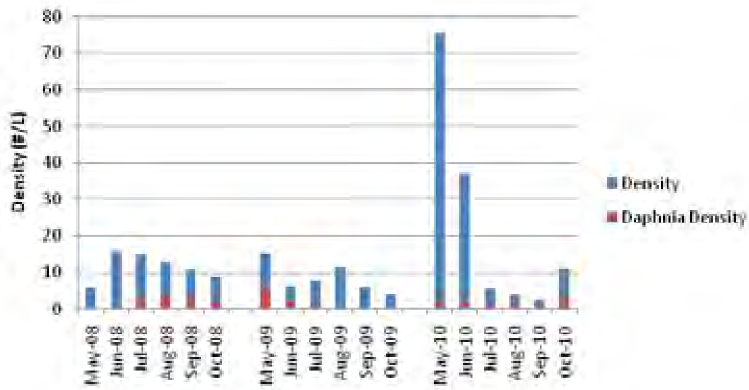


Figure 25: Mean monthly zooplankton biomass (ug/L)

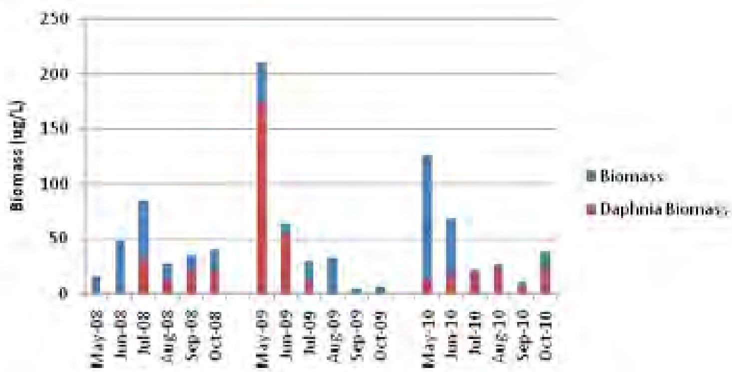
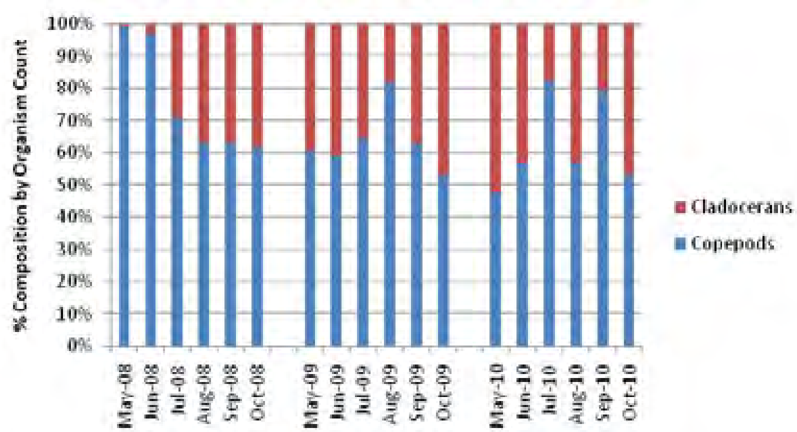


Figure 26: Percent composition by organism count



Zooplankton density is typically highest in the spring for Cedar Lake and declines across the season (Figure 24). Typically the zooplankton densities remain below 15 organisms per liter; however, in the spring of 2010, much higher numbers were seen. It was a very warm spring in 2010 and ice off dates around Cedar Lake were late March/early April; however, the observed chl-*a* during the May 2010 sampling date did not indicate high levels of algal growth (Figure 20). High density of zooplankton in May 2010 was caused by a *Bosmina* sp. bloom. *Bosmina longirotris* made up 50% of the sample by number in May 2010. This was likely caused by the early ice out/ warm spring as noted above. Since they are very small, they don't contribute as much to biomass and they also are not as efficient at grazing algae as Daphnia are. Daphnia collected were often low in number but large in size, making up a significant portion of the biomass measured on each date (Figure 25). The zooplankton community over the three year period of record tends to be dominated by copepods. Cladocerans do appear to make up a larger proportion of the community later in the summer, but rarely exceed the copepod population (Figure 26).

Trophic State Index

One way to evaluate the trophic status of a lake and to interpret the relationship between TP, chl-*a*, and Secchi disk transparency is Carlson's Trophic State Index (TSI) (Carlson 1977). TSI values are calculated as follows:

Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

Chlorophyll-*a* TSI (TSIC) = 9.81 ln (chl-*a*) + 30.6

Secchi disk TSI (TSIS) = 60 – 14.41 ln (SD)

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, chl-*a*, and Secchi (Figure 27). In general, the TSI values are in fairly close correspondence with each other. The TSI values also correspond with observations for 2008-2010. Based on an average TSI score of 40 Cedar Lake would be characterized as mesotrophic.

Figure 27: Carlson's Trophic State Index for Cedar Lake

TSI < 30 Classical Oligotrophy: Clear water, oxygen throughout the year in the Hypolimnion, salmonid fisheries in deep lakes.

TSI 30 – 40 Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

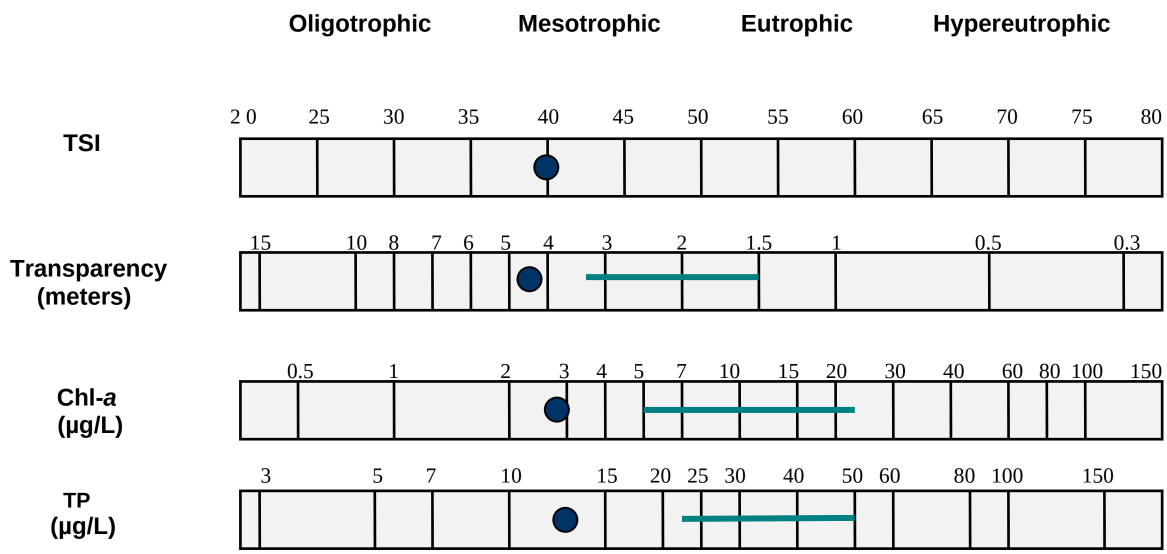
TSI 40 – 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 – 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 – 70 Dominance of blue-green algae, algal scums probable, extensive Macrophyte problems.

TSI 70 – 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.

TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



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Ecoregion Range: 2008-2010

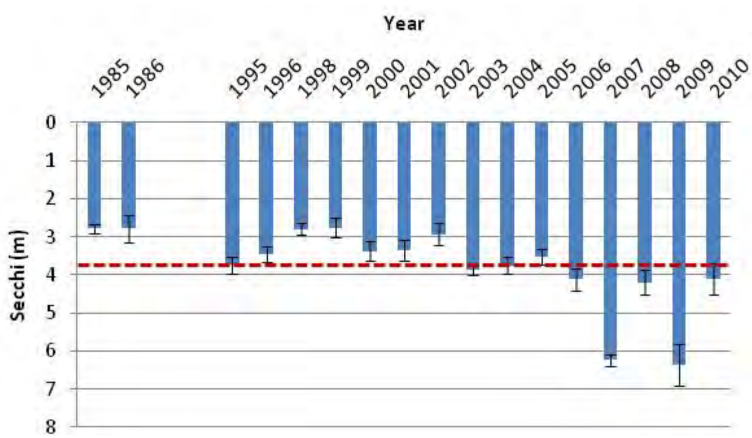
Trophic Status Trends

One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in STORET. A review of data in STORET indicates there is a good amount of data for Cedar Lake to describe annual variability and to statistically assess trends for Secchi transparency (Figure 28). The water chemistry dataset is much less robust; prior to the start of monthly sampling in 2008, the most recent water chemistry was collected in 1985 and 1986 by MPCA as part of the ecoregion reference lake dataset sampling (Figure 29).

In general, for trend assessment we seek a minimum of eight years of consistent data. During the most recent trend analysis completed using Citizen Lake Monitoring Program Secchi data, it was determined that Cedar Lake was experiencing improving transparency, estimated at 0.9 meters (3 feet) per decade. Based on Figure 28, Secchi has been greater than the long-term mean and highly variable from 2006-2010.

Figure 28: Cedar Lake long-term summer-mean Secchi disk depth

Long-term mean noted by dashed red line



While insufficient data exists to calculate a statistically significant trend based on TP or chl-*a* data, a review of the data record does provide useful information (Figure 29). TP is considerably lower now than it was in the 1980s at the time of the ecoregion reference dataset collection. Chl-*a*, in contrast, did not exhibit a dramatic decline over the same period, as it was already low (less than 5 ug/L) during the ecoregion reference sampling. Based on yearly TSI averages calculated for 1985 through 2010, Cedar Lake has historically been classified as mesotrophic (Figure 30).

At this point there is no obvious explanation for the reduction in TP and increase in Secchi; however potential factors could include change in fishery over time (Figure 10) or perhaps reduced P loading from the watershed as the result of land use changes or implementation of best management practices. Further work will be needed to explain the observed trends in TP and Secchi.

Figure 29: Cedar Lake long-term summer-mean total phosphorus and chlorophyll-*a*
Long-term average indicated by dotted line; standard error of the mean noted for each year.

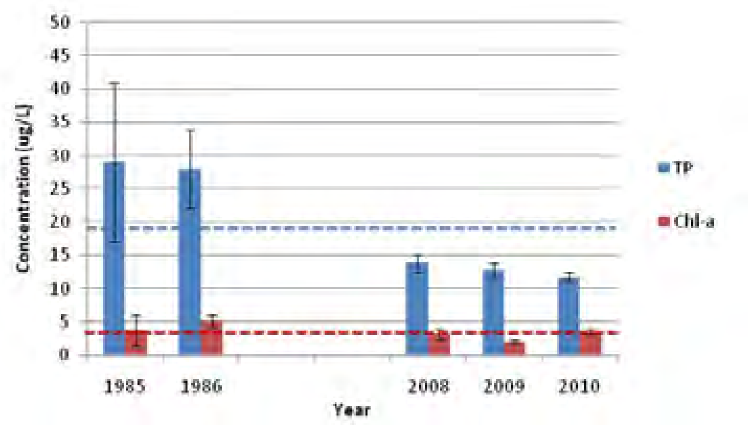
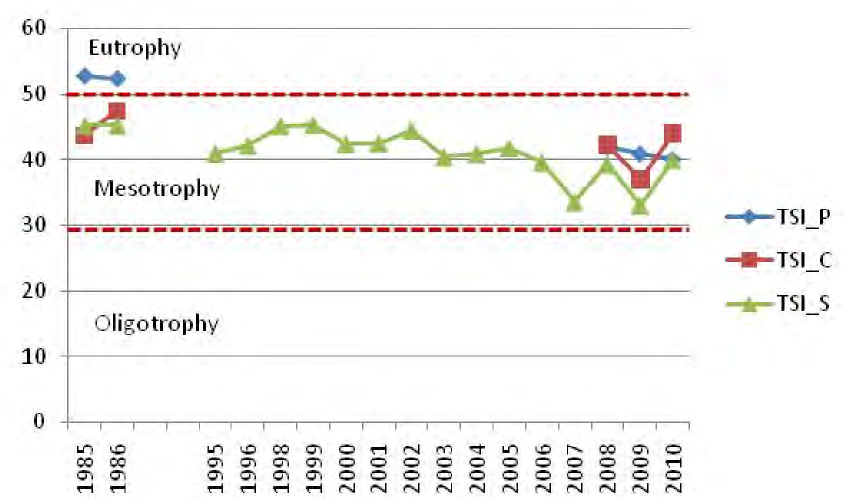


Figure 30: Cedar Lake trophic status trend



Modeling

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water that enters the lake. To analyze the 2008-2010 water quality of Cedar Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. A comparison of MINLEAP predicted vs. observed values is presented in Table 10.

MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). The model predicts in-lake TP from these inputs and subsequently predicts chl-*a* based on a regression equation of TP and Secchi based on a regression equation based on chl-*a*. For analysis of Cedar Lake, MINLEAP was applied as a basis for comparing the observed summer (2008-2010) TP, chl-*a*, and Secchi values with those predicted by the model based on the lake size and depth and the area of the watershed.

Cedar Lake is located in the NCHF ecoregion and the model was run using NCHF ecoregion-based inputs. The observed TP and chl-*a* values for Cedar Lake are better than expected but within the standard error of the model predictions; observed Secchi is significantly better than predicted. The estimate of "background" TP (Vighi & Chiaudani) is slightly higher than the modern-day TP for Cedar Lake but again is within the error estimate of the model (Table 10).

Table 10: MINLEAP model results for Cedar Lake

Parameter	2008-2010 Cedar Lake Observed	MINLEAP Predicted NCHF Ecoregion
TP (µg/L)	13	20
Chl-*a* (µg /L)	2.9	5
Secchi (m)	4.3	2.9
P loading rate (kg/yr)	-	117
P retention (%)	-	89
P inflow conc. (µg/L)	-	185
Water Load (m/yr)	-	0.65
Outflow volume (hm^3/yr)	-	0.63
Residence time (yrs)	-	17
Vighi & Chiaudani	-	18

303(d) Assessment and Goal Setting

The federal Clean Water Act requires states to adopt water quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming. The standards are set on a wide range of pollutants, including bacteria, nutrients, turbidity and mercury. A waterbody is "impaired" if it fails to meet one or more water quality standards.

Under Section 303(d) of the Clean Water Act, the state is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e. impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion. In addition, either the chl-*a* concentration for the lake must exceed the standard or the Secchi data for the lake must be below the standard. A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a waterbody is listed, an investigative TMDL study must be conducted to determine the sources and extent of pollution, and to establish pollutant reduction goals needed to restore the resource to meet the determined water quality standards for its ecoregion. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL studies in Minnesota.

Cedar Lake is considered to be fully supporting aquatic recreation use standards (Table 11). The lake should be protected against increases in total phosphorus. This implies the importance of minimizing nonpoint source (e.g. stormwater) runoff into the lake. Also, shifts in the plant community may increase the presence of algal blooms. DNR has confirmed the presence of curly-leaf pondweed; should curly-leaf become dominant in the lake it could have very negative consequences for Cedar's water quality and overall ecology.

Table 11: Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005)

Cedar Lake 2008-2010 and long-term means provided for comparison. Applicable standard in bold.

Ecoregion	TP µg/L	Chl-*a* µg/L	Secchi meters
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2b)	**< 40**	**< 14**	**> 1.4**
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	< 60	< 20	> 1.0
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7
Cedar Lake 2008-2010	13	2.9	4.3
Cedar Lake Long-term mean	19	3.5	3.8

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Appendix A

Ice-on and Ice-off Records for Cedar Lake

Lake Name	Lake ID	Ice Off Date	Ice On Date
Cedar Lake	49-0140		12/5/1994
Cedar Lake	49-0140	4/22/1995	11/25/1995
Cedar Lake	49-0140	4/28/1996	11/23/1996
Cedar Lake	49-0140	4/22/1997	11/20/1997
Cedar Lake	49-0140	4/2/1998	12/22/1998
Cedar Lake	49-0140	4/8/1999	12/21/1999
Cedar Lake	49-0140	3/25/2000	12/2/2000
Cedar Lake	49-0140	4/22/2001	12/10/2001
Cedar Lake	49-0140	4/22/2002	12/5/2002
Cedar Lake	49-0140	4/13/2003	
Cedar Lake	49-0140		12/14/2004
Cedar Lake	49-0140	4/8/2005	
Cedar Lake	49-0140		12/3/2007
Cedar Lake	49-0140	4/30/2008	
Cedar Lake	49-0140	4/20/2009	

Appendix B

Lake Surface Water Quality Data for Cedar Lake for 2008-2010.

All water quality data can be accessed at: http://www.pca.state.mn.us/data/eda/STresults.cfm?stID=49-0140&stOR=MNPCA1

Lake Name	Lake ID	Sample Date	Site ID	Secchi	TP	Chl-*a*	Alkalinity	Chloride	TKN	N02+NO3	Color, Apparent	TSS
				Meters	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	PCU	mg/L
Cedar	49-0140	5/6/2008	202	2.2	34	16.9	170	5.93	0.73	0.13	10	4
Cedar	49-0140	6/16/2008	202	2.4	18	5.22			0.69	<0.05		
Cedar	49-0140	7/15/2008	202	4	12	1.66	150	5.93	0.56	<0.05	5	1.2
Cedar	49-0140	8/12/2008	202	4.2	13	2.55			0.55	<0.05		
Cedar	49-0140	9/10/2008	202	5.3	12	3.64				<0.05		
Cedar	49-0140	10/7/2008	202	4	11	8.73	150	5.77	0.5	<0.05	10	
Cedar	49-0140	5/28/2009	202	5.8	13	0.95	170	6.2	0.63	<0.05	5	2
Cedar	49-0140	6/24/2009	202	8.3	10	1.09			0.51	<0.05		
Cedar	49-0140	7/29/2009	202	4.9	15	1.8	150	5.84	0.47	<0.05	5	1.6
Cedar	49-0140	7/29/09 FR	202	4.9				5.8		<0.05		
Cedar	49-0140	8/25/2009	202	4	14	2.83			0.76	<0.05		
Cedar	49-0140	9/23/2009	202	5	12	2			0.46	<0.05		
Cedar	49-0140	10/5/2009	202	4.5	17	5.1	160	6.31	0.56	<0.05	5	1.6
Cedar	49-0140	5/20/2010	202	3.3	16	2.45	170	6.35	0.7	<0.05	10	2.4
Cedar	49-0140	6/9/2010	202	4	12	2.18	170	6.34	0.61	<0.05	10	1.6
Cedar	49-0140	7/27/2010	202	2	13	3.49	150	6.3	0.63	<0.05	5	4.4
Cedar	49-0140	7/27/10 FR	202					6.28		<0.05		
Cedar	49-0140	8/24/2010	202	3	10	4.02	150	6.33	0.63	<0.05	5	2.4
Cedar	49-0140	9/27/2010	202	4.5	12	4.33	160	6.35	0.66	<0.05	10	1.6

Appendix C

Zooplankton Data 2008 – 2010

	Density	Biomass	Copepods	Cladocerans	Daphnia Density	Daphnia Biomass
Cedar Lake	#/L	ug/L	#/L	#/L	#/L	ug/L
May-08	6	15	118	1	0	0
Jun-08	16	49	201.5	5.5	0.1	0.3
Jul-08	15	85	91.5	38	2.8	31.4
Aug-08	13	27	66.5	39	3.6	14.0
Sep-08	11	35	52.5	30.5	2.9	19.8
Oct-08	9	40	78.5	48.5	1.9	19.4
May-09	15	211	152.5	100	6.0	174.0
Jun-09	6	65	65.5	45.5	2.4	54.0
Jul-09	8	29	89	48.5	1.0	12.6
Aug-09	12	32	75	17	0.3	0.8
Sep-09	6	5	59	35	0	0
Oct-09	4	6	54	47	0.2	0.4
May-10	76	125	191	211	2.0	12.8
Jun-10	37	68	121	93	2.2	17.0
Jul-10	5	21	75.5	16	0.9	18.1
Aug-10	4	26	56	42.5	1.6	21.1
Sep-10	2	11	58.5	15.5	0.3	6.4
Oct-10	11	39	100	87	3.3	21.1