THE RESTORATION OF SILVER LAKE,

MANITOWOC COUNTY

March 2009

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Wisconsin Department of Natural Resources:
[1]Bureau of Science Services, [2]Northeast Region, [3]Bureau of Fish Management, [4]Manitowoc County Lakes Association, and [5]Bureau of Watershed Management

PUB-SS-1046 2009

ACKNOWLEDGEMENTS

Many people assisted with this project. One of the most important was Tom Ward, formerly of the Manitowoc County Land and Conservation Department. Without his leadership and guidance this project likely would not have been completed. Tim Rasman, Silver Lake College, and the Holy Family Convent were early supporters of this project. Hans Pearson also helped in the early stages. Dr. John Panuska provided some of the hydrologic and phosphorus budget modeling that was important for designing the project. Randy Behnke was instrumental in collecting phytoplankton and zooplankton samples, as well as Secchi depths following the restoration work. Steve Surendonk helped conduct the fish surveys.

Funding and support for this project was from a large variety of sources. Without the contributions from the large number of organizations this project would not have been possible. Supporters are listed on the next page.

Financial Supporters:		
- WI DNR Lake Protection Grants		$306,512
- WI DNR Environmental Damage Compensation Fund		$40,000
- WI Dept. of Transportation		$100,000
- Mtwc. County Planning & Parks - WI Waterways Comm. Grant		$26,500
- WI Dept. of Agriculture, Trade & Consumer Protection		$25,000
- U.S. Fish & Wildlife Service		$20,000
- U.S. EPA sec. 319 incremental grant		$22,171
- Town of Manitowoc Rapids		$5,000
- Silver Lake Rehabilitation District		$5,714
- Sportsman's Group Matches for Planning & Parks Grant		
Cleveland Fish & Game	$500	
East Coast Gobblers Association	$300	
Fish & Game Association	$10,000	
Francis Creek Sportsman's Club	$500	
Izaak Walton League	$5,000	
Manitowoc Bass Club	$200	
Manitowoc Conservation Sportsmen	$400	
Manitowoc County Coon Hunters	$100	
Manitowoc County Lakes Association	$300	
Manitowoc Rifle & Pistol Club	$200	
Manitowoc Unit of Fish & Game	$1,000	
Maribel Sportsman's Club	$500	
N.E. Great Lakes Sport Fishermen	$500	
Pigeon Lake Sportsman's Club	$500	
Pine River Sportsman's Club	$1,000	
Private Donations	$590	
Reedsville Sportsman's Club	$250	
Trout Unlimited	$500	
Two Rivers Fish & Game	$500	
Whitelaw Sportsman's Club	$1,000	
WI Deer Hunters/Local	$1,000	
WI Deer Hunters/State	$1,000	
		$25,840
Total Contributions:		**$576,737**

In Kind Service & Material Donators:

- Manitowoc County Highway Commission
- Town of Manitowoc Rapids
- Town of Newton
- Manitowoc County Soil & Water Conservtion Department
- R & J Fricke Inc.
- Foth & Van Dyke
- William Fessler
- Manitowoc County Lakes Association - Silver Lake Park Planning Committee

EXECUTIVE SUMMARY

Silver Lake is a 69 acre, 43 foot deep lake in Manitowoc County, WI. It has a long history of frequent and persistent, noxious algal blooms resulting in occasional fish kills. This degraded condition stemmed from diverting Silver Creek into the lake in 1936 and subsequent intensive agriculture in the watershed.

Although many best management practices were installed in the watershed during the period 1985-1995, the lake continued in a degraded condition. A partial stream diversion in 1995 failed to significantly improve the lake's water quality. In 2001 Silver Creek was completely diverted away from the lake. In order to reduce internal sources of phosphorus, the fish community (largely rough fish) was eradicated with rotenone in 2003 and a more desirable fishery was stocked into the lake. The principal fish added to the lake were northern pike, largemouth bass, walleye, yellow perch and forage fish. An alum treatment was done in early 2004 to seal the deep water sediments from phosphorus release.

These restoration efforts were very successful with phosphorus levels being reduced 85% and algal levels being reduced 90%. The alum treatment nearly eliminated release of phosphorus from the deep water sediments. Although the water quality improvements have been significant, the submerged aquatic vegetation community has not responded as well. The number of species, diversity, and areal coverage has been less than expected.

Part of the reasoning for the structuring of the fish community was to facilitate the growth of large zooplankters which would restrict the amount of algae through grazing pressure. The zooplankton community was slow to respond but after 4-5 years the community contained many large zooplankters. The fish community after 5 years has developed into one dominated by yellow perch and bluegills, with lesser amounts of walleye, northern pike, and largemouth bass.

In June 2008 frequent and persistent rains resulted in Silver Creek flooding, resulting in the lake level rising over 3 feet. This flooding brought much sediment and associated nutrients into the lake. This event provided a test of the resiliency of the lake to a major perturbation. Phosphorus concentrations increased from 26 to 57 $\mu g\ L^{-1}$. Algal concentrations were higher than previous years and water clarity was worse. The sediment that entered the lake during the flooding may have partially buried the alum layer as phosphorus release from the deepwater sediments was much higher than in the years immediately following the alum treatment. The lake will be monitored in future years to determine the long-term impact of the flooding.

Perhaps the best indication of the improvement in the lake has been the large increase in fishing pressure as well as investment in improving the county park that is located on the shore. The parking lot is filled most weekends with vehicles of people recreating on the lake. The park has undergone significant landscaping improvements including removal of old and diseased trees and replacement with a more diverse herbaceous community, establishment of a prairie, removal of terrestrial exotics, e.g. honeysuckle and buckthorn, and establishment of a rain garden. Footpaths with sitting benches, a pavilion, gazebo, shoreline restoration through a DNR grant, seven educational signs and two fishing piers have also been placed in the park. Park usage has returned to levels not experienced for several decades and it has become a popular designation for families and other nearby residents.

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Introduction

Silver Lake is located just west of the city of Manitowoc. Since the 1950s, the water quality of the lake was heavily degraded with frequent and large algal blooms and occasional winter and summer fish kills. Conditions were so bad that in 1998 the lake was placed on the 303(d) list of impaired waters, due to phosphorus pollutants resulting from agriculture, internal loading, and local landuse. This is a list of water bodies that are degraded to the point they do not meet fishable and swimmable standards.

In order to improve the lake's water quality, a number of measures were undertaken in the last 10 years. These included rerouting the incoming stream so that most of the water did not enter the lake. The fishery was eradicated and restocked. After these other measures had been completed, an alum treatment was done to reduce internal loading of phosphorus from the bottom sediments. This report documents these restorative techniques and the response of the lake to these changes.

Lake Characteristics

The surface area of Silver Lake is 69 acres with a maximum depth is 43 feet and the mean depth is 16 feet. The lake is a drainage lake that had a permanent stream entering the east basin near the lake's outlet (Figure 1) until the stream was diverted in 2002. An intermittent stream enters the lake's western basin. Before 2000 the lake's watershed size was 12,147 acres with 71% of the landuse in agriculture (Figure 2). The entire lake is a wildlife refuge and substantial numbers of waterfowl visit the lake in the spring and fall. No hunting is permitted. The use of outboard motors is also prohibited.

The large watershed size combined with the high level of agricultural activity resulted in high nutrient loadings to the lake. Consequently the lake experienced very high phosphorus levels resulting in large and frequent algal blooms. Phosphorus levels in the lake at times exceeded 350 $\mu g\ L^{-1}$ and were much higher than other lakes in the county (Figure 3). These high algal levels resulted in frequent winter fish kills since the 1950s as well as occasional summer fish kills. Consequently, the fish community was highly degraded. The predominant fish were carp, bullheads, small panfish and gizzard shad.

A phosphorus budget was constructed for the lake that indicated 67% of the phosphorus entering the lake came from Silver Creek (Figure 4). The other major source was internal loading, from the deep water sediments during anoxic periods as well as nutrient release from rough fish, e.g. carp.

A sediment core was taken from each basin to reconstruct the water quality history of the lake. The core from the East Basin showed that the lake began to degrade during the 1930s. It was found that

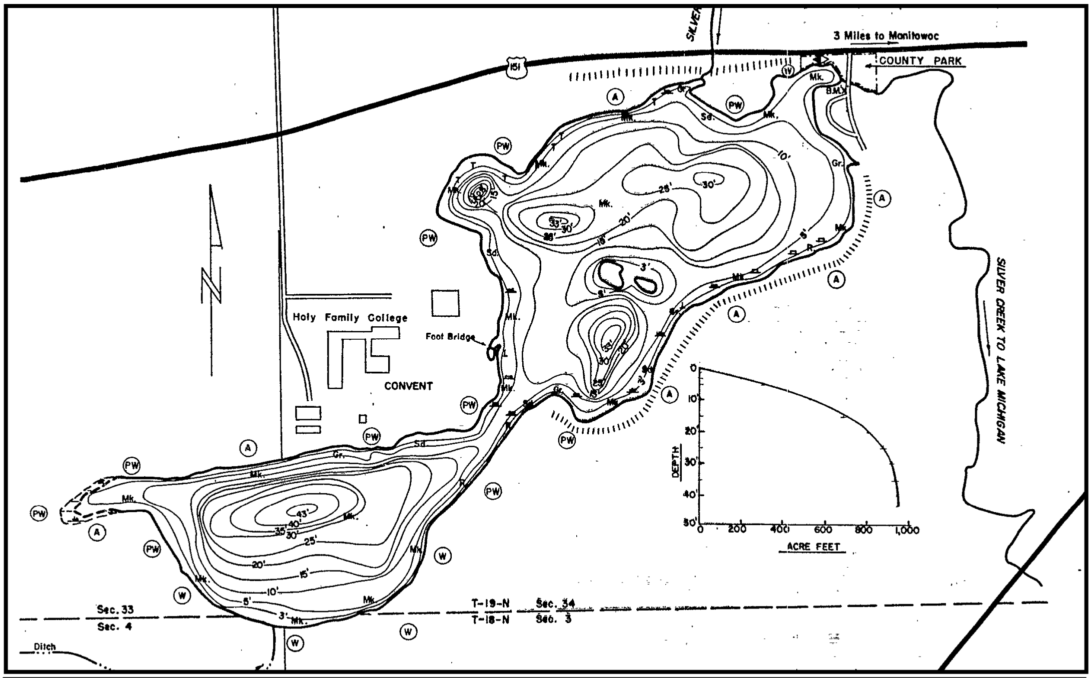


Figure 1. Morphometric map of Silver Lake showing where Silver Creek entered the lake prior to the partial diversion in the mid-1990s. The partial diversion directed the inlet towards to the outlet. (See Figure 7 for more detail.)

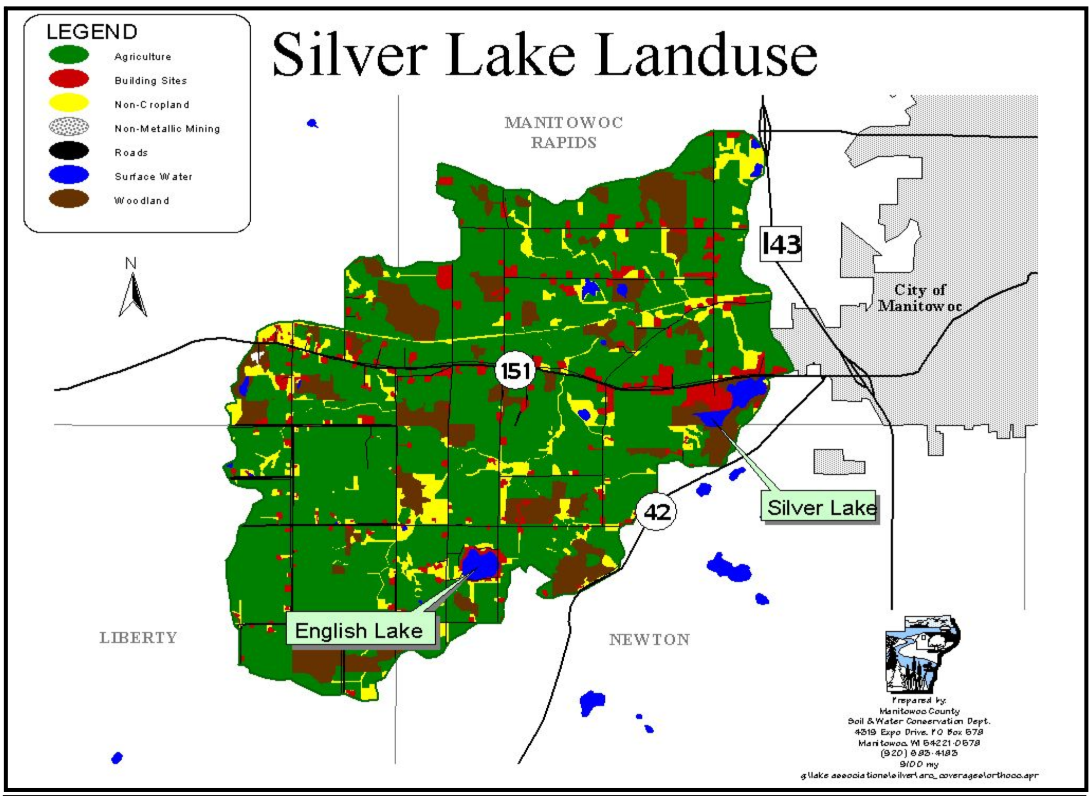


Figure 2. The Silver Lake watershed and landuse prior to the full diversion in 2001. The major landuse in the watershed was agricultural row crops. The diversion reduced the size of the watershed from 12,000 to 475 acres.

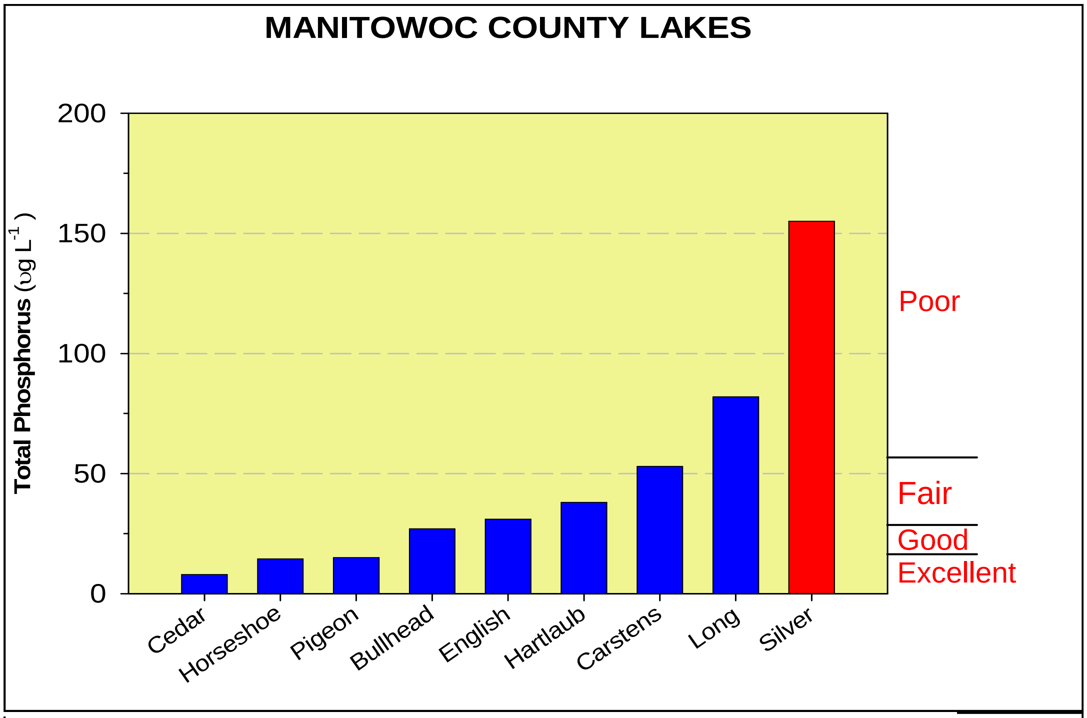


Figure 3. A comparison of phosphorus values in Silver Lake to concentrations in other Manitowoc lakes during the 1990s. Phosphorus levels in Silver Lake placed the lake in the poor category.

when Highway 151 was rebuilt in 1935, Silver Creek was routed directly into Silver Lake. Prior to this time a wetland had separated the creek from the lake. Undoubtedly, during periods of high flow the stream would have discharged into the lake but other times most of the water would have bypassed the lake or the water would have been filtered through the wetland. After the diversion of the stream into the lake, the sedimentation rate increased (Figure 5). The rate was variable during the next 70 years depending upon the amount of runoff from the watershed. The rate was especially high during the period from 1960-1985. This was because agriculture, in general, intensified during the period with increased mechanization and switch to cash cropping. During the last 20 years, conservation practices have been instituted which has reduced sediment runoff. Unfortunately the sedimentation rate increased by an order of magnitude as a result of the stream diversion and increase in agriculture intensity during the last half of the twentieth century.

Along with the increase in the sedimentation rate was an increase in soil erosion (indicated by an increase in aluminum deposition) as well as phosphorus deposition (Figure 5). Again these increases were the result of diverting the stream into the lake as well as increased agricultural activity. With the increase in delivery of sediment and phosphorus to the lake, the inlake phosphorus levels significantly increased (Figure 5). The inlake phosphorus concentrations were estimated using changes in the diatom community. Diatoms are a type of algae that are preserved in the sediments. Different species live under differing phosphorus levels so changes in the community can be used to estimate past phosphorus levels. The phosphorus levels in the early part of the twentieth century were about 40 µg L^{-1}. Soon after the stream was diverted into the lake, levels increased to around 100 µg L^{-1}. They continued to increase and reached levels exceeding 200 µg L^{-1} in the 1960s (Figure 5).

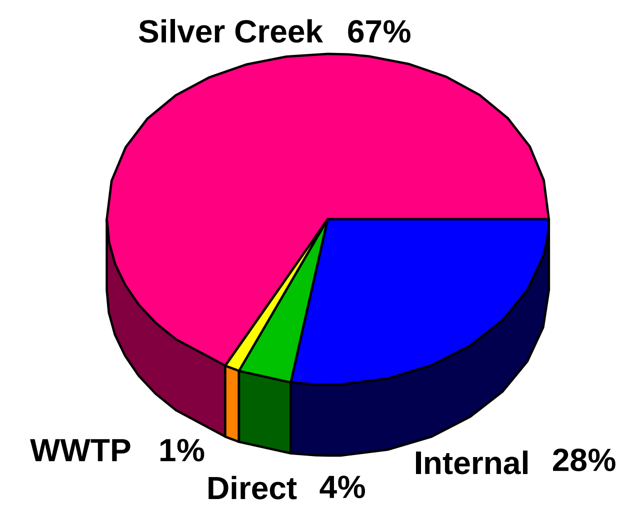


Figure 4. Phosphorus budget for Silver Lake. The largest source of phosphorus was Silver Creek with internal loading, primarily from rough fish and deep water sediments.

Past Rehabilitation Efforts

After public access was acquired Silver Lake was treated with toxaphene in the fall of 1965 to control the rough fish population found in the lake. A total of 10,000 pounds of rough fish were removed from the lake with carp making up 40% of the harvest and bullheads the remaining 60%.

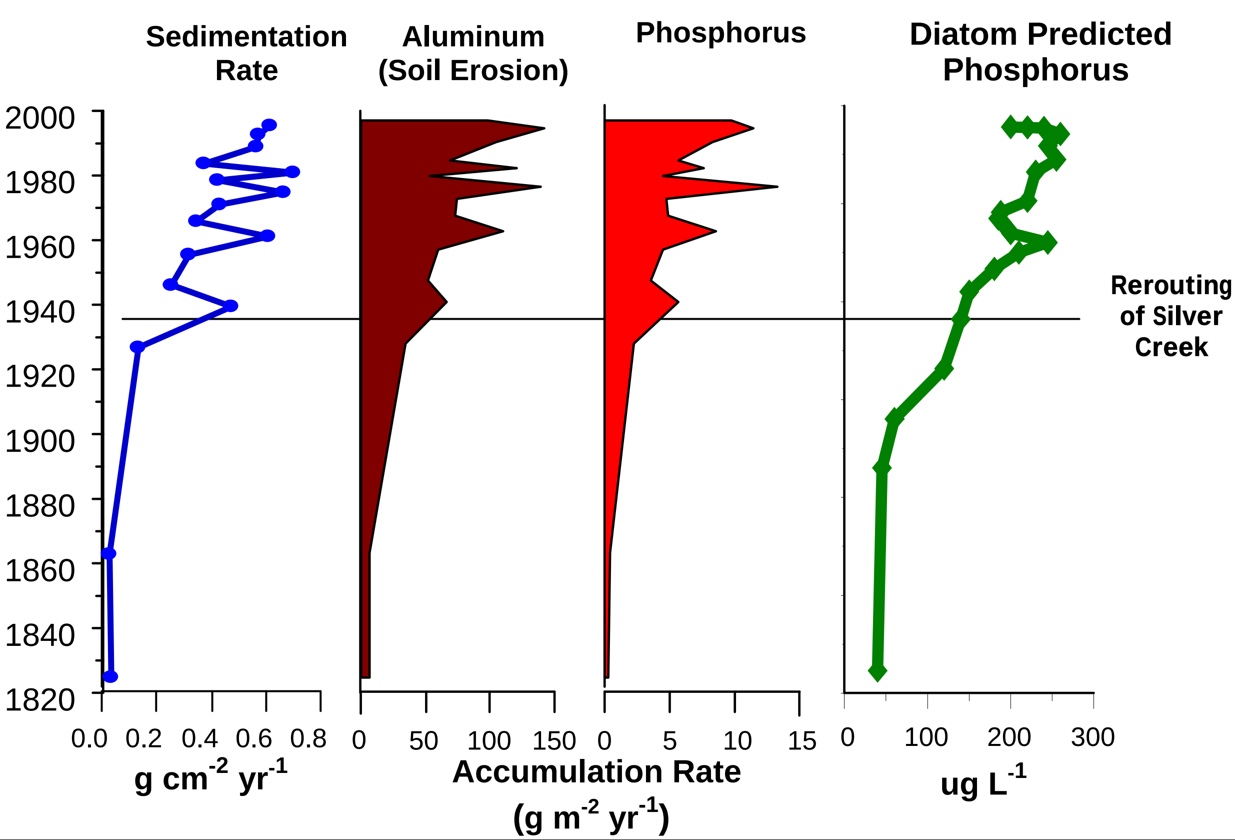


Figure 5. Results from sediment core collected in the East Basin showing the adverse impact of rerouting Silver Creek into the lake in 1936. This resulted in a large increase in sediment and phosphorus entering the lake.

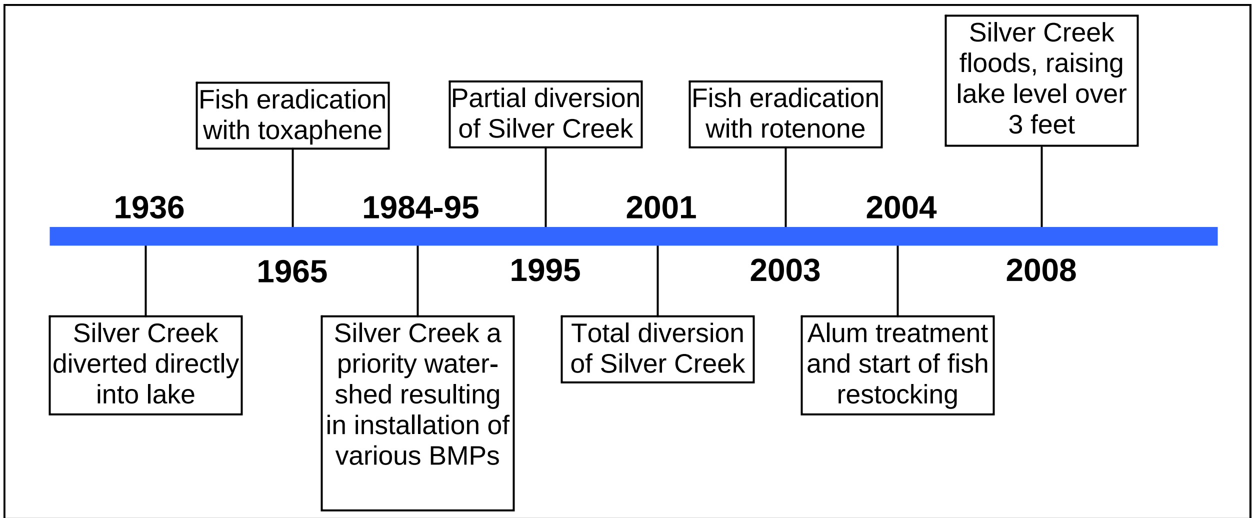


Figure 6. Timeline of important activities affecting Silver Lake during the last 75 years.

Minor components of the catch were largemouth bass and northern pike. Very few panfish were observed. After treatment, the lake was restocked with 4000 legal sized brook trout to provide immediate fishing, northern pike fry, fingerlings and adults, walleye fry and fingerlings, yellow perch adults, and largemouth bass fingerlings and adults. Concurrently, a fish weir was proposed to block the upstream migration of carp from Lake Michigan into Silver Lake. Plans were dropped when revisions that allowed the structure to withstand a twenty year flood, made the cost too high for the lake association.

Carp and bullhead quickly re-entered the lake and once again dominated the fish community. An electroshocking survey in August 1967 indicated carp and bluegill were the dominant species with northern pike, walleye, and largemouth bass present in much lower numbers. A May 1974 electroshocking survey had similar results with numerous carp and white sucker seen. Sixteen yellow perch and one northern pike were also caught. Other fish observed were black bullhead, bluegill and pumpkinseed.

It is clear from earlier studies that Silver Lake experienced poor water quality conditions because of a number of sources. The primary problem was the input of nutrients and sediment from Silver Creek. Because of the input of large amounts of nutrients the lake experienced poor oxygen levels at times causing fish kills and resulting in an unbalanced fishery dominated by rough fish. Because of decades of high nutrient loading, a significant amount of internal phosphorus loading was occurring. It was clear that the primary problem was Silver Creek and agricultural landuse within the watershed. Initially, conservation practices were instituted on the landscape to reduce the runoff of sediment and nutrients to the stream. This began in 1984 with the awarding of a Wisconsin Fund Non-point Watershed Project called the Seven Mile Silver Creek project. The project ended in 1995 with the installation of 13 barnyard treatment systems, 14 restored wetlands, and 5 sediment basins to trap sediments. Three easements to install permanent grass buffers along stream channels were also installed.

However, phosphorus loadings to the lake remained high.

In the mid 1990's a project was initiated to align the inlet to the lake more directly toward the outlet hoping to bypass a significant portion of the loading. The presence of deep peat deposits (> 90 ft.) and close proximity to the Hwy 151 right of way precluded a complete diversion at this time. In addition, a bridge downstream of the lake was replaced and stream obstructions were removed to provide better downstream flow. This redirection can be seen by comparing where Silver Creek enters the lake in Figure 1 with Figure 7. Also, at this time additional agricultural best management practices were installed in the lake's direct drainage area. However monitoring and a winter fish kill in 1996 and a summer kill in 1999 indicated that the improved watershed conditions and the partial diversion had not significantly improved in the lake.

Contemporary Rehabilitation Efforts

In order to improve the lake's water quality and thus make the lake a more desirable environment for recreational use the restoration effort was redoubled. A team of stakeholders including Manitowoc County Land and Water Conservation Department, Wisconsin Department of Natural Resources, Silver Lake Protection and Rehabilitation District, Holy Family Convent, and area sportsman clubs was convened to set scientific and sociologic goals and facilitate the full restoration of the lake. These steps are summarized in Table 1.

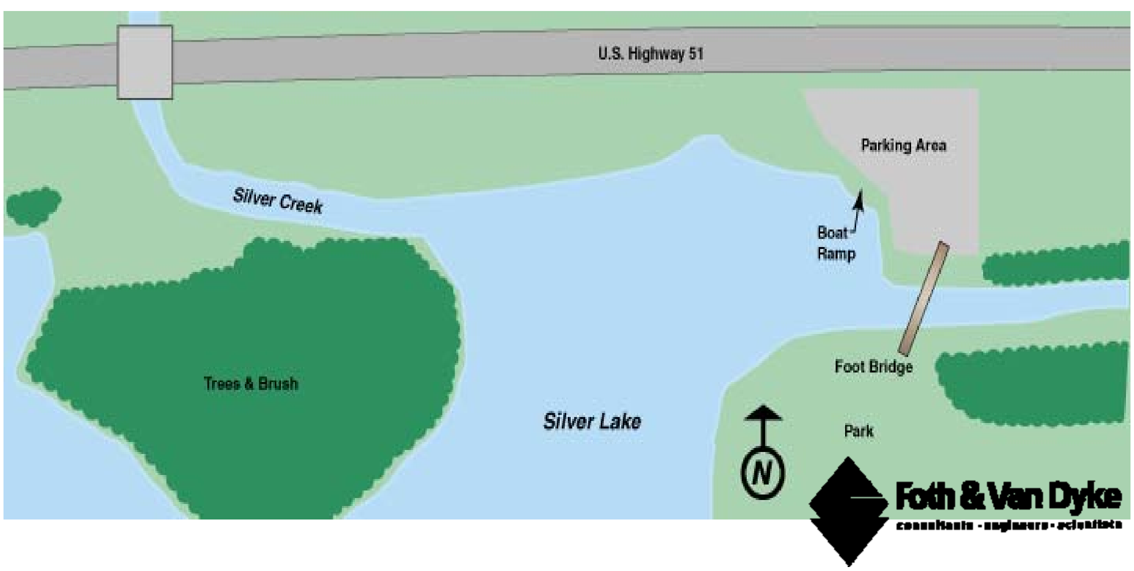


Figure 7. A rendering of the partial diversion of Silver Creek which was completed in the mid-1990s.

Table 1. Restoration Steps.

Step 1: Design project with partners
Step 2: Set scientific and sociologic goals
Step 3: Divert stream from lake
Step 4: Eradicate fishery
Step 5: Apply alum to reduce internal loading
Step 6: Restock a diverse fish community
Step 7: Improve county park
Step 8: Evaluate success of project

Since the major source of nutrients was Silver Creek, it was clear that the first step should be the full diversion of the stream away from the lake, effectively reducing the lake's watershed from over 12,000 acres to 475 acres. This diversion was designed by the engineering firm of Foth & Van Dyke and involved placing a berm between the stream and the outlet (Figure 8). The berm was constructed of clay material that was placed on the lake bed. It was anticipated that a significant amount of organic muck would be displaced by the installation of the berm. The diversion was started in 2001. A picture of the berm under construction is shown in Figure 9. More muck was displaced than was anticipated which completely blocked access to the lake (Figure 10). Removal of the muck caused delays and additional money had to be found but the stream diversion was completed in early 2002. As part of the stream diversion, a box culvert was installed so that an existing boat ramp could be replaced. In addition the public parking lot was expanded and a foot bridge across the creek that provided access to the County Park was replaced. The lake outlet structure was constructed with a flap gate so water could leave the lake when necessary but not let water or fish from the creek enter the lake. However,

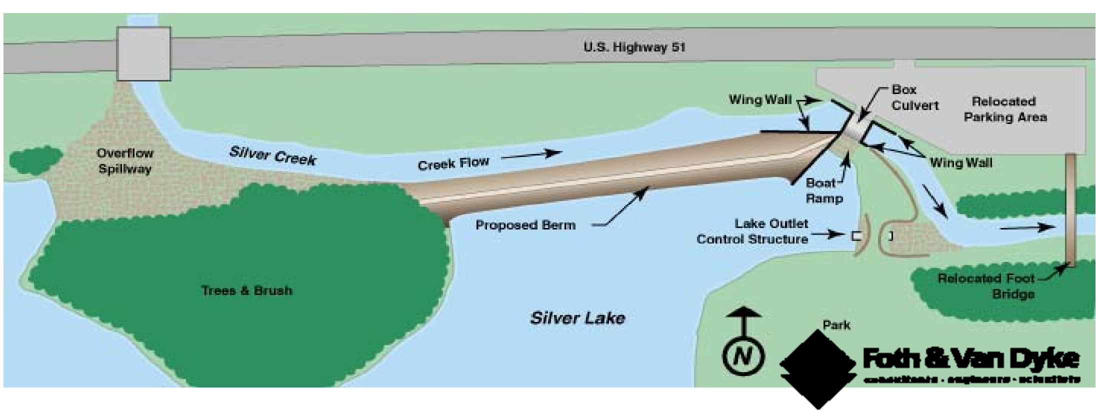


Figure 8. A rendering of the full diversion of Silver Creek which was completed in 2001.

Figure 9. Picture of the rerouted stream with the berm between the stream and the lake on the left and HWY 151 on the right.

to guard against downstream flooding the berm was designed with a reinforced overtopping structure so that water from the stream could enter the lake during 25 year runoff events and greater. It was believed that a fully restored Silver Lake would develop enough resiliency to withstand infrequent mixing with the creek's higher nutrient levels, sediment loads and invasive fish species.

The next step was to eradicate the lake's fishery and restock it. The eradication was accomplished in the fall of 2003 using rotenone. Most of the fish that were found to be present in the lake were gizzard shad, carp, and bullheads. Very few gamefish were recovered.

Figure 10. Picture of displaced lakebed sediment caused by the construction of the berm separating Silver Creek from the lake. Much of the displaced sediment was removed to allow access to the lake.

Since the rotenone treatment, the lake has been stocked with a variety of fish species that would promote self-sustaining populations, be desired by anglers and help maintain the water quality goals of the restoration project. To date, six species and over 180,000 individual fish have been stocked (Table 2).

In addition to fish stocked by the State, several species of fish, most notably bluegill and pumpkinseed were found in the lake during surveys since 2004. It is suspected that these fish were illegally stocked into the lake following the rotenone treatment. Following an overtopping event in the spring of 2004,

Table 2. Fish stocked into Silver Lake since the 2003 rotenone treatment.

	2004	2005	2006	2007	2008	Total
Largemouth Bass	10,000 (small fingerling)	1,000 (small fingerling)	--	--		11,000
Walleye	1,000 (small fingerling)	1,400 (large fingerling)	1,360 (small fin-gerling)	1,358 (small fin-gerling)	1,358 (small fin-gerlin g)	6,479
Northern Pike	2,000 (small fingerling)	6,800 (small fingerling)	--	--	6,800 (small fin-gerlin g)	15,600
Northern Pike	100 (large fingerling)	--	3,000 (large fingerling)	--		3,100
Yellow Perch	4,000 (small fingerling)	1,000 (small fingerling)	--	--		5,000
Fathead Min-now	150,000 (adult)	--	--	--		150,00 0
White Sucker	250 (adult)	250 (adult)	322 (adult)	--		822
Total	167,350	10,450	4,682	1,358	8,158	191,99 8

it was feared that alewives had also re-entered the lake. This species targets and feeds upon large zooplankton. Since the water quality goals of the project hinged on maintaining a fishery that would not feed on large zooplankton to a significant extent, additional study was done to find out how many of these fish were present. This study was conducted by Dr. Tom Hrabick of U. of Minnesota-Duluth. Using acoustical survey techniques, he found no alewives. His report can be found in Appendix C.

The next step was to add aluminum sulfate (alum). The purpose of this treatment was to reduce internal loading of phosphorus from the deep water sediments. When the bottom waters become devoid of oxygen, phosphorus that is bound with iron in the sediments is released into the overlying water. In the presence of oxygen iron is in the ferric form which is insoluble. When oxygen levels are very low the ferric iron is converted into the ferrous form which is soluble in water. Since a large portion of the phosphorus in the sediments is bound with iron, when the iron diffuses from the sediments into the overlying water, the phosphorus associated with it also enters the water column. Applying alum results in the iron bound phosphorus becoming bound with aluminum instead. Aluminum and the associated phosphorus is insoluble and remains so in the absence of oxygen. There phosphorus is not released from the deep water sediments even when the overlying water becomes anoxic.

In the spring of 2004 alum was applied at a rate of about 50 g m^2 over the lake at water depths greater than 10 feet. This treatment occurred over a 2 day period. Figure 11 is a picture of the barge applying the alum.

Figure 11. Picture of the barge applying alum to reduce phosphorus release from the deep water sediments.

In June 2008, the Silver Lake area experienced a large amount of rain over several days resulting in an extreme runoff event and discharge of Silver Creek into the lake. This discharge would simulate how the lake and stream related prior to the diversion in 2002. Figure 12 shows pictures of the stream discharging into the lake. Beyond assessing the success of the restoration, this project was able to assess the resiliency of the lake to a major perturbation. While there was overtopping for a few hours in 2004 and 2007 it was only for a few hours and likely did not introduce a significant amount of nutrients to the lake.

Lake response to restoration efforts

Various parameters were sampled in Silver Lake to assess the success of this project. These measurements include the trophic variables, phosphorus, chlorophyll, and water clarity; zooplankton community, fish community, and macrophyte community.

Trophic Variables

Prior to the stream diversion, phosphorus levels in both basins were extremely high. Maximum levels were variable between years depending upon how much runoff occurred from Silver Creek. Summer mean phosphorus levels often exceeded 200 µg L^{-1} (Figures 3, 13a, 14a) placing the lake in the hypereutrophic category. Following the stream diversion, phosphorus levels were much lower but they were still high enough to cause frequent nuisance algal blooms. The mean concentration in 2003, the first year following diversion, was 106 µg L^{-1}. Following the fish eradication and alum treatments, the phosphorus levels dropped even more to a summer mean of 34 µg L^{-1} in the East Basin and 35 µg L^{-1} in the West Basin in 2004 (Figures 13a, 14a). For 3 years (2005-07) the summer mean phosphorus concentrations was less than 30 µg L^{-1}. This places Silver Lake in the mesotrophic range and the concentration was close to levels present in the lake prior to 1900. With the overtopping of the berm in 2008, phosphorus levels were the highest they had been since the completion of the restoration effort. The summer mean increased to 44 and 45 µg L^{-1} in the East and West basins, respectively. The higher levels in 2008 were undoubtedly the result of the heavy rains in June as concentrations were higher in the surface waters the rest of the summer compared with 2007 (Figure 15).

As with phosphorus, chlorophyll concentrations were very high prior to the stream diversion (Figure

Figure 12. Pictures of Silver Creek overflowing the berm and entering Silver Lake in June 2008. The water level of the lake was raised over 3 feet during this time.

13b, 14b, Table 3). Values were around 100 µg L^{-1} which are levels expected in hypereutrophic lakes. After the diversion, chlorophyll levels were reduced to near 40 µg L^{-1} which are still high. The first year after the alum treatment and fish restocking the values were still somewhat elevated, especially in August when levels exceeded 35 µg L^{-1}. During the period 2005-07, the mean summer chlorophyll concentrations were below 10 µg L^{-1}, which place the lake in the mesotrophic range. In 2008 the higher phosphorus levels following the heavy June rains resulted in higher chlorophyll levels (Table 3).

Water clarity was measured using a 20 cm black and white Secchi disc. Generally, clarity was measured at least monthly during the summer. Some years it was measured twice per month. Secchi depth prior to the diversion was very poor, being about 0.7 meters. After the diversion the water clarity did not improve much. However after the alum treatment and fish eradication and restocking it greatly improved. During the period 2005-07, water clarity was much better than prior to the restoration work and was at its highest level in 2007. The improving water clarity is partially in response to the changing zooplankton community. As will be discussed later, in 2007 there was more large zooplankton which help reduce the algal levels and thus improve water clarity. Even though phosphorus and algal levels were higher in 2008 compared with the previous 3 years, this was not reflected in the water clarity. The mean summer Secchi in both basins was better than in 2005 or 2006 (Table 3). This was primarily due to exceptional water clarity in May and early June. Water clarity in late July and August was less than 1 meter.

The purpose of the alum treatment was to reduce the migration of phosphorus from the bottom sediments when the bottom waters lack oxygen. Without oxygen, iron and its associated phosphorus is

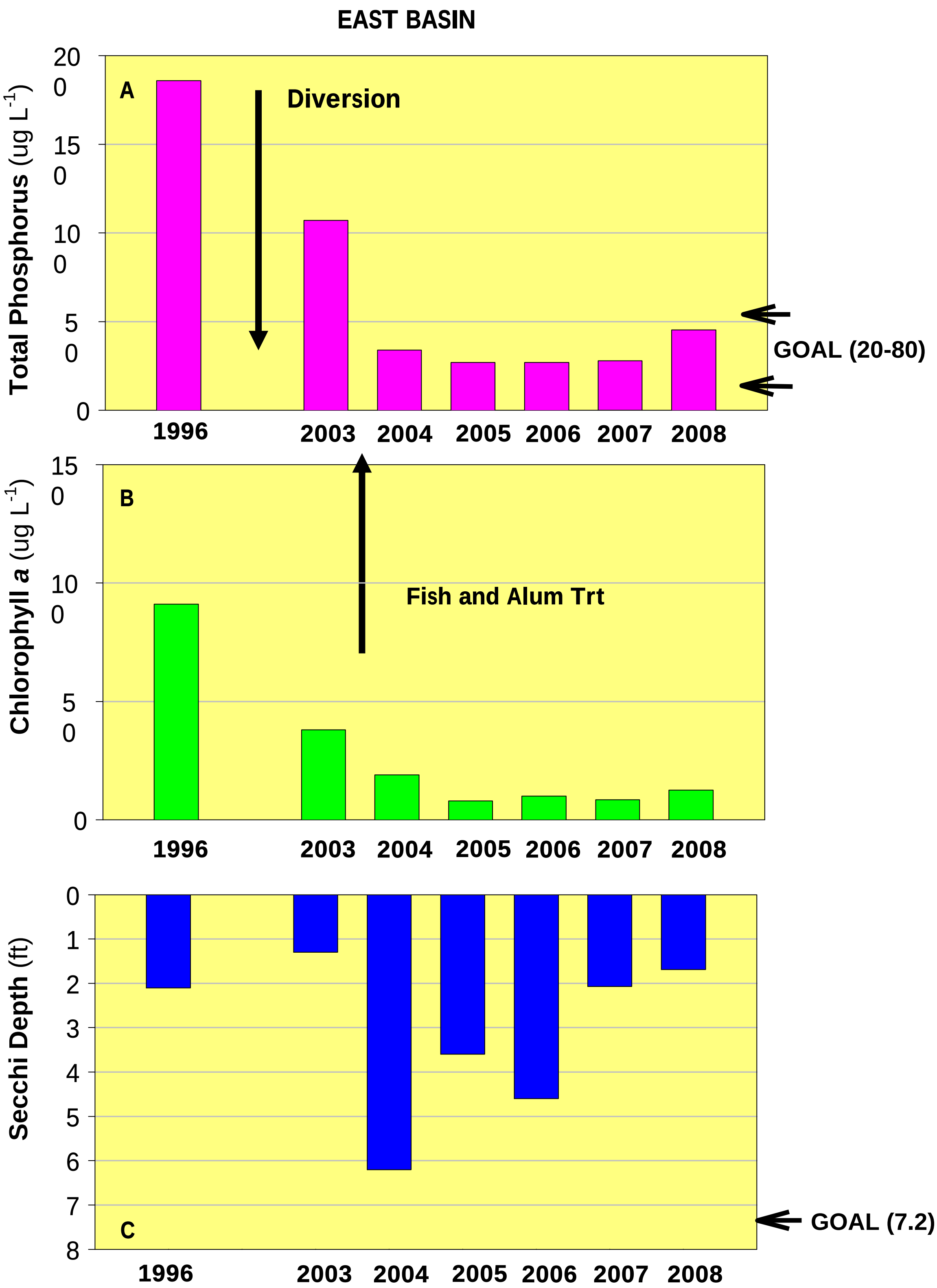


Figure 13. Summer mean values for the trophic variables in the East Basin. Phosphorus concentrations meet the project goals while water clarity has not met the goal.

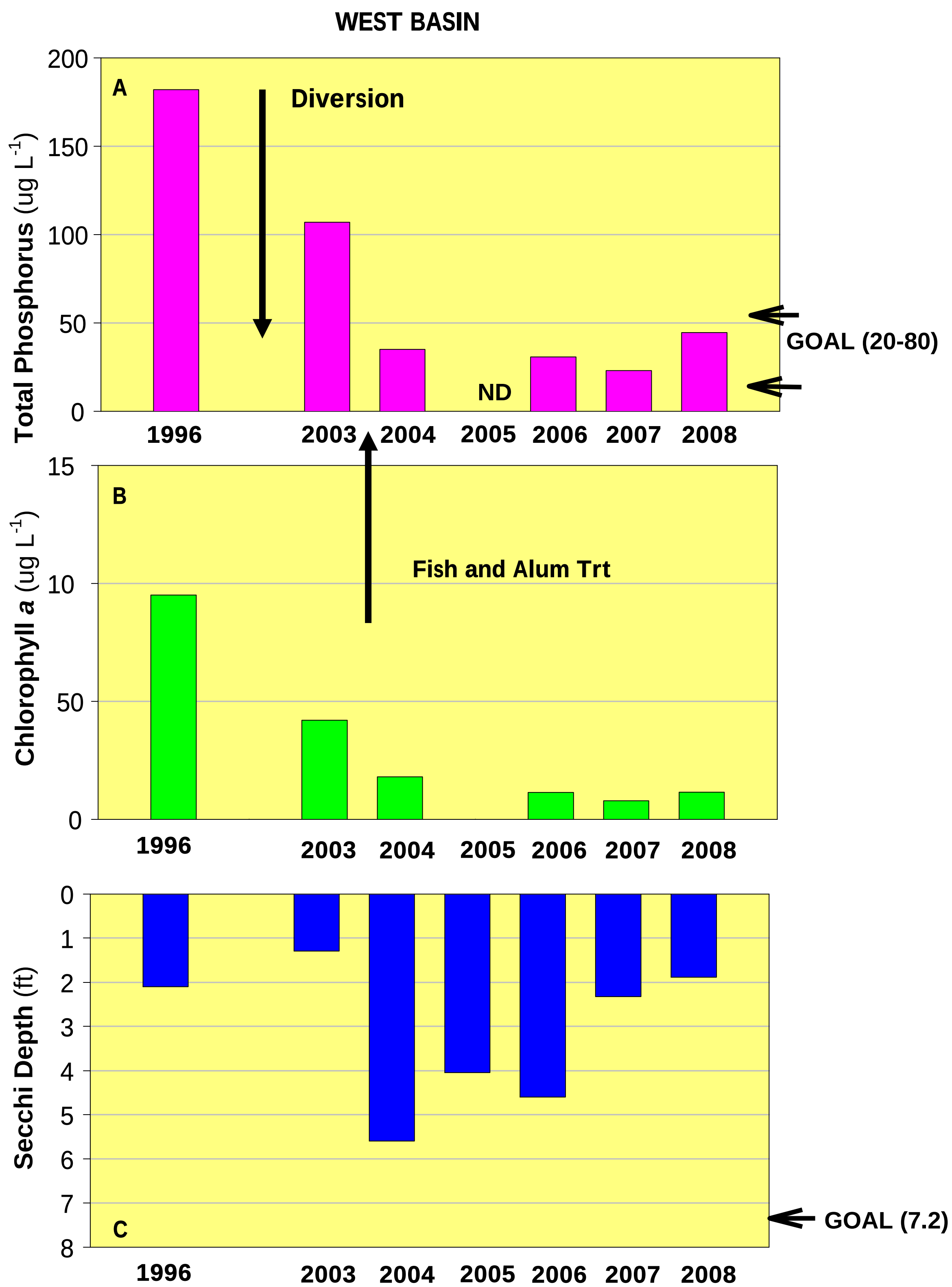


Figure 14. Summer mean values for the trophic variables in the West Basin. Phosphorus concentrations meet the project goals while water clarity has not met the goal.

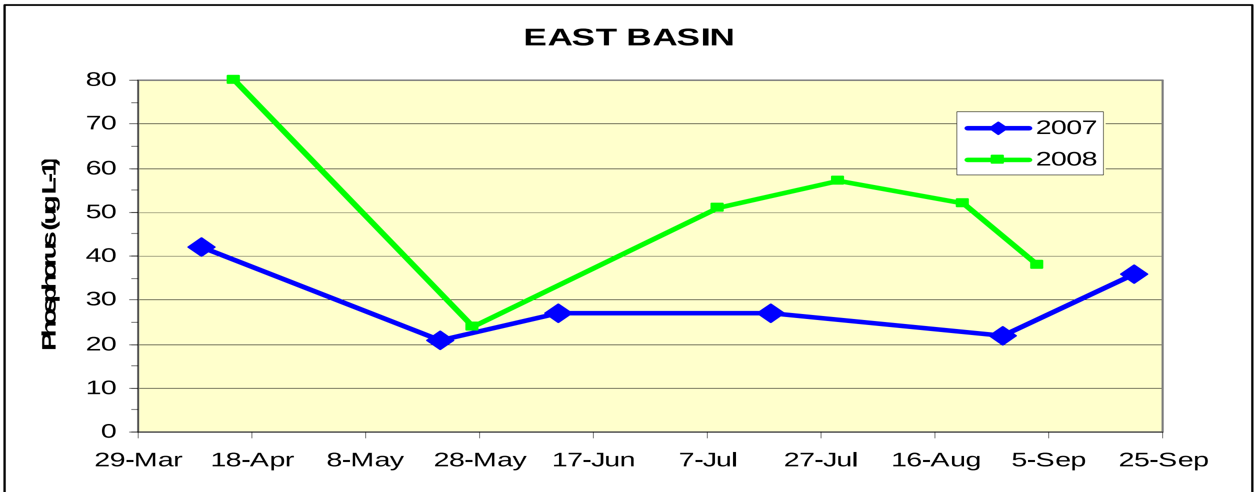


Figure 15. Comparison of phosphorus concentrations in the East Basin in 2007 and 2008. In June 2008, heavy rains caused Silver Creek to overflow its banks into the lake. These heavy rains caused the lake level to rise over 3 feet.

Table 3. Summer mean concentrations of the trophic variables. The stream was diverted in 2002 and fish eradication and alum treatment occurred between the summers of 2003 and 2004. The stream overtopped its banks and discharged into the lake during June 2008.

	Total Phosphorus ($\mu g\ L^{-1}$)	**Chlorophyll** ***a*** ($\mu g\ L^{-1}$)	**Secchi Depth** (ft)
	EAST BASIN		
1996	186	91	6.9
2003	107	38	4.3
2004	34	19	6.2
2005	27	8	3.8
2006	27	10	4.6
2007	28	8	6.8
2008	45	13	5.5
	WEST BASIN		
1996	182	95	6.9
2003	107	42	4.3
2004	35	18	5.6
2005	ND	ND	ND
2006	31	11	4.5
2007	23	8	7.6
2008	44	12	6.2

released from the sediments into the overlying water. The aluminum in alum binds with the phosphorus that is associated with iron. Since aluminum, unlike iron, does not become soluble when the oxygen disappears, the phosphorus remains in the sediments.

Phosphorus profiles were collected from both basins near the end of stratification annually in 2003 through 2008 with the exception of 2007. The purpose of this sampling was to measure the effectiveness of the alum treatment. Prior to the alum treatment phosphorus concentrations in the bottom waters of the East Basin exceeded 2.0 mg L^{-1} (Figure 16) and the increase in phosphorus mass from internal loading was 212 kg (Table 4). The three years following the alum treatment (2004-06), the phosphorus levels in the bottom waters were significantly less, never exceeding 250 µg L^{-1}. More importantly, the increase in the mass of phosphorus was about 1 kg. In 2008 the stream overtopped its

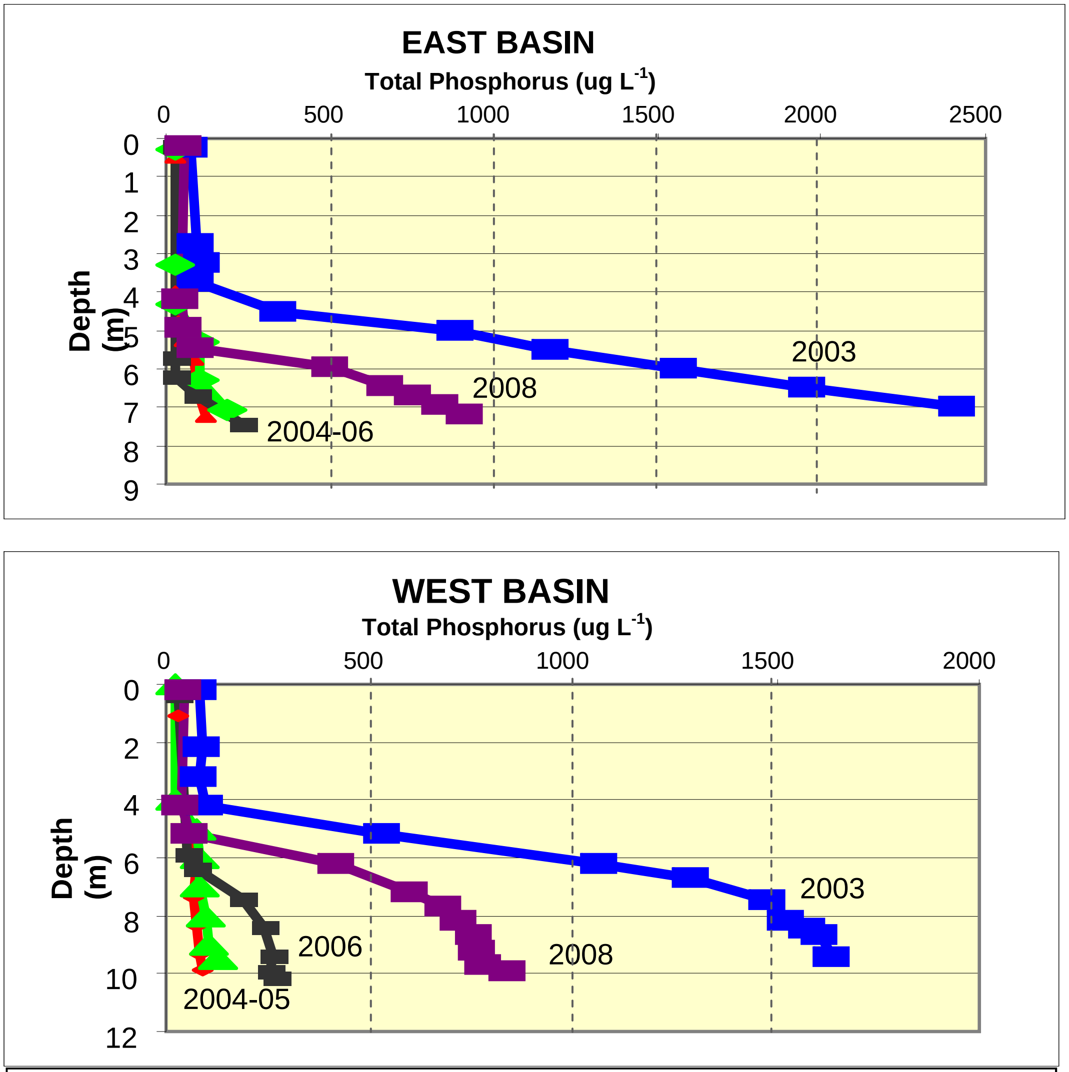


Figure 16. Phosphorus profiles in both basins showing the effectiveness of the alum treatment. The alum treatment was very effective at reducing P concentrations in the bottom waters until the flooding in 2008.

banks in June of a significant amount of water entered the lake. In 2008 the phosphorus levels in the bottom waters were much higher in mid-September, with concentrations approaching 1 mg L^{-1} just above the sediments. Although phosphorus levels were not as high as prior to the alum treatment (2003) they were much higher than at any time during the period 2004-2006.

Table 4. Amount of internal loading (kg) in each basin from the bottom sediments. The year 2003 was prior to the alum treatment while 2008 was the year of the flood.

	East Basin	West Basin
2003	212	79
2004	0	0
2005	0	0
2006	1	6
2008	63	41

Macrophytes

Macrophytes (submerged aquatic plants) are an important component of the lake's ecosystem. They provide habitat for fish and insects as well as stabilize sediments. The water clarity goal that was set for the lake (7.2 ft) was established to provide sufficient clarity to allow macrophyte growth to 11 feet, covering 30-49% of the lakebed.

Only one macrophyte survey (1979) was conducted prior to the stream diversion. Surveys have been conducted each year following the completion of the restoration work. The 1979 survey found no submerged species and the emergent species (cattails, sedges, and rushes) were very sparse. It was felt this was the result of low water clarity and the disruptive behavior of carp and bullheads.

In 2004 there were two submerged species which were relatively sparse in coverage. The two submerged species were *Potamogeton foliosus* (leafy pondweed) and *Stuckenia pectinata* (sago pondweed). The lone floating-leaf species was *Nuphar variegata* (spatterdock). In 2005 four species were present. As in 2004 they were *P. foliosus* and *N. variegata* but *S. pectinata* had been replaced by *Chara* (musk grass) which is actually an alga but grows like a macrophyte. In 2006 the distribution of plants had expanded and there was further expansion in coverage in 2007. Also in 2007 three new species were also found. They were *Vallisneria americana* (wild celery), *Utricularia minor* (small bladderwort), and *Lemna minor* (duckweed). A complete list of macrophytes found in 2007 is given in Table 5.

The amount of littoral zone that is inhabited by macrophytes and their diversity is disappointing but it did seem to be expanding. In 2007 the percentage of littoral zone with plants had increased to 21 per-

Table 5. Silver Lake 2007 Aquatic Plant Species List

Common Name	Scientific Name	Growth Form
Muskgrass	*Chara* sp.	Submergent
Leafy pondweed	*Potamogeton foliosus*	Submergent
Spatterdock	*Nuphar variegate*	Floating leaf
Filamentous algae	*Unknown species*	Submergent
Swamp loosestrife	*Decodon verticillatus*	Emergent
Hardstem bulrush	*Schoenoplectus acutus*	Emergent
Wild Celery	*Vallisneria americana*	Submergent
Duckweed	*Lemna minor*	Free-floating
Small bladderwort	*Utricularia minor*	Submergent
Cattail	*Typha* sp.	Emergent

cent and the maximum depth of growth was the greatest recorded at 11.5 feet. The aquatic plant community did not seem to change much in 2008. However, the maximum depth of plant growth decreased to only 8.4 feet and invasive aquatic plant species (Eurasian watermilfoil) was detected at the boat landing. The 2008 macrophyte report is included in Appendix A.

Zooplankton

One of the goals of the project was to structure the fish community such that large zooplankton would be abundant during much of the year. This was done by stocking many piscivorous fish so the number of plantivorous (plankton eating) fish would be relatively low. Since zooplankton eat algae and larger species eat more, it was hoped that if enough large zooplankton were present, algal levels would be lower than would be expected given the phosphorus concentration. This process is called biomanipulation. The zooplankter that is most desirable is *Daphnia* (water flea), particularly the larger species of this genera. An example of a large *Daphnia* is shown in Figure 17.

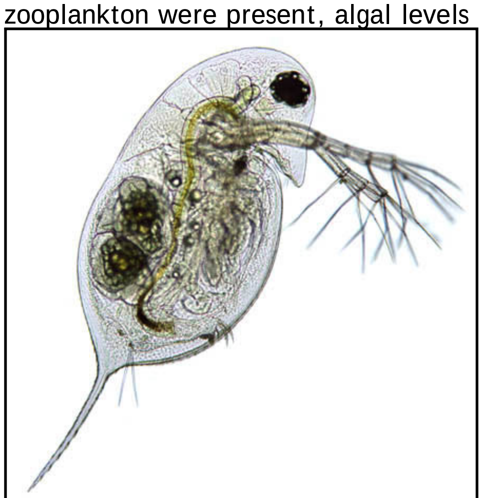


Figure 17. Picture of zooplankter *Daphnia*. Part of the restoration effort was to promote the growth of these organisms to reduce the algal population .

Unfortunately there is not any zooplankton data for the lake prior to the stream diversion. The first year that zooplankton samples were taken was in 2005. The biomass of the zooplankton for most of the summer was equally divided between the most desirable zooplankter, *Daphnia*, and other small Cladocera (Figure 18a). The dominant *Daphnia* were *D. pulicaria* and *D. galeata mendotae*. The most common small Cladocerans were *Bosmina longirostris* and *Diaphanosoma birgei*. While the most common *Daphnia* was the taxa most desired because of its large size, the overall numbers of the zooplankton were much lower than what was hoped for.

In 2006, zooplankton numbers were higher in mid-June compared with 2005 but the biomass was much lower the rest of the summer (Figure 18b). The same *Daphnia* were present as were found in the previous year. Unfortunately most of the cladocerans were small species that eat less algae than the desired larger *Daphnia*.

In 2007, for the first time the zooplankton community was found in higher numbers for much of the summer (Figure 18c). The dominant taxa were the larger *Daphnia* which eat the most algae. Unlike the previous years, the dominant *Daphnia* was *D. galeata mendotae*. In 2007 it appears that the zooplankton community was finally reaching the level that was hoped for, although the *Daphnia* were not as large as desired. The mean length was about 0.8 mm. It would be better if their length was over 1.0 mm but at least they were present in relatively high numbers for most of the summer (Figure 19).
In 2008 the zooplankton community was much different than it was in 2007 (Figure 18d). At the end of May there was a large bloom of large bodied *D. pulicaria* in both basins. The biomass was higher by an order of magnitude than anything measured in the previous years. Part of the reason for the large biomass was the larger size of the *Daphnia*. While *D. galeata mendotae* had been the dominant *Daphnia* in previous years, in early 2008 *D. pulicaria* was dominant. The *Daphnia* finally achieved the desired length of over 1 mm (Figure 19). The length was similar to that in Lake Delavan which was a lake with a successful biomanipulation in the 1990s.

Unfortunately the overtopping of the stream banks in June apparently had an adverse effect on the zooplankton community. In July and the rest of the summer *Daphnia* were absent from the community and the cladocerans present were the small taxa *B. longirostris* and *Ceriodaphnia lacustris*. The length of these small cladocerans was smaller than measured in previous years (Figure 19). *D. birgei*, which was an important late summer component of the cladoceran community in previous years was not present in 2008.

The copepod community was also different in 2008 compared with previous years. While calanoid zooplankton were common in 2006 and more so in 2007 (Figure 20), they were found in low numbers in 2008. These zooplankton are largely herbivorous and are large enough to consume a significant amount of algae. The cyclopoid copepods were not found in large numbers prior to 2008 but they was very common in late summer 2008. The most common cyclopoid was *Tropocyclops prasinus*. This is one of the smallest planktonic cyclopoids and therefore it is not able to consume large amounts of algae.

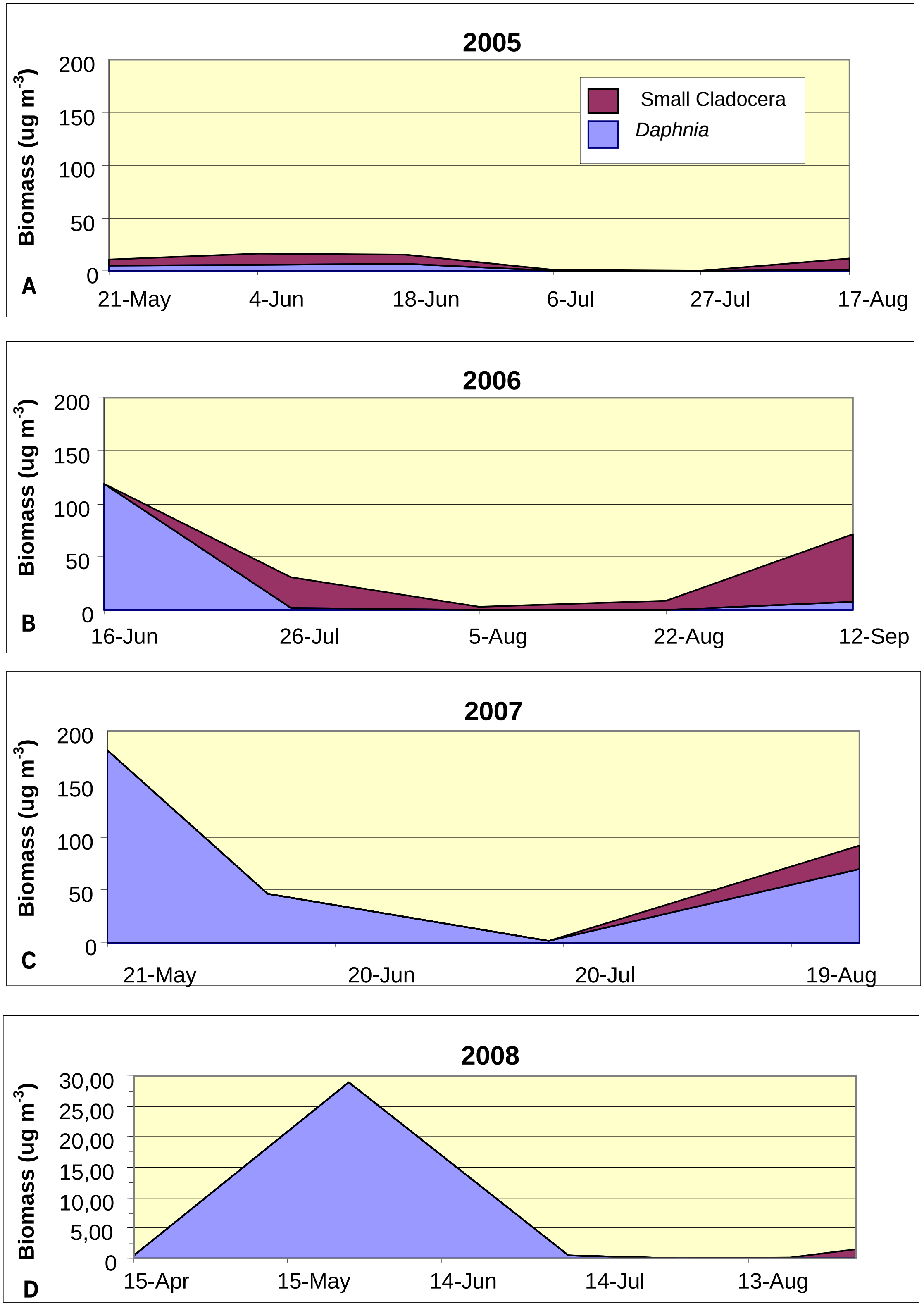
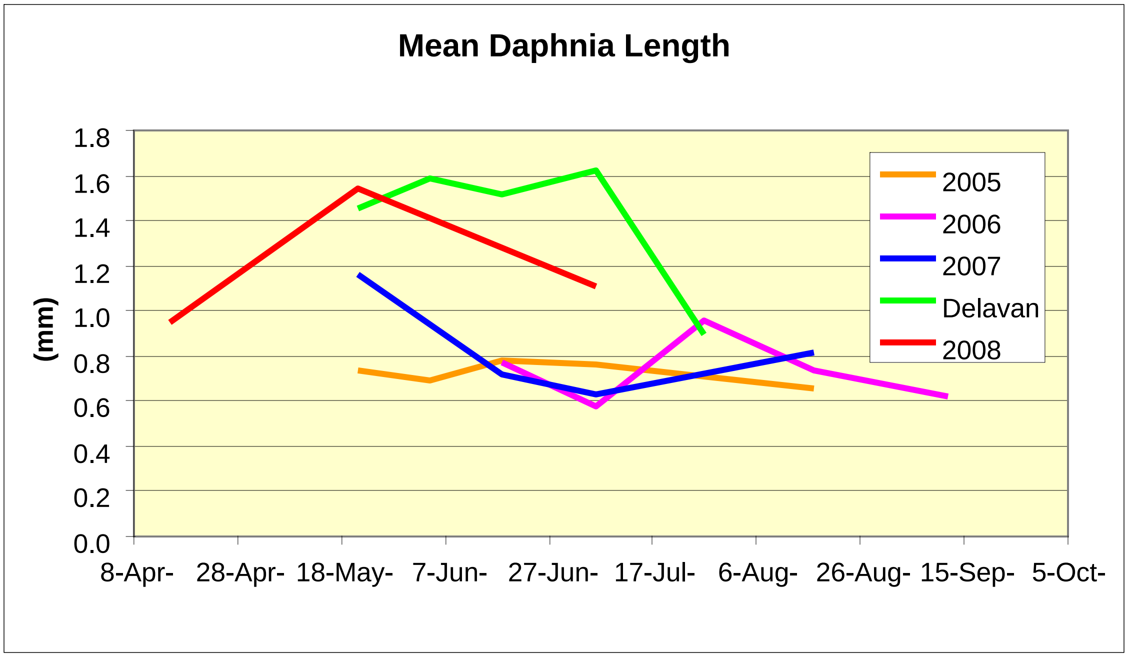


Figure 18. Cladocerans in Silver Lake for the years following completion of the restoration steps. Note the very high numbers of *Daphnia* in 2008 prior to the flood.

The much smaller size of the zooplankton community in 2008 compared with previous years, especially 2007, indicates fish predation is likely having an adverse affect on the zooplankton community. Since fish feed on the larger zooplankton, only the small species are able to survive under heavy pre-



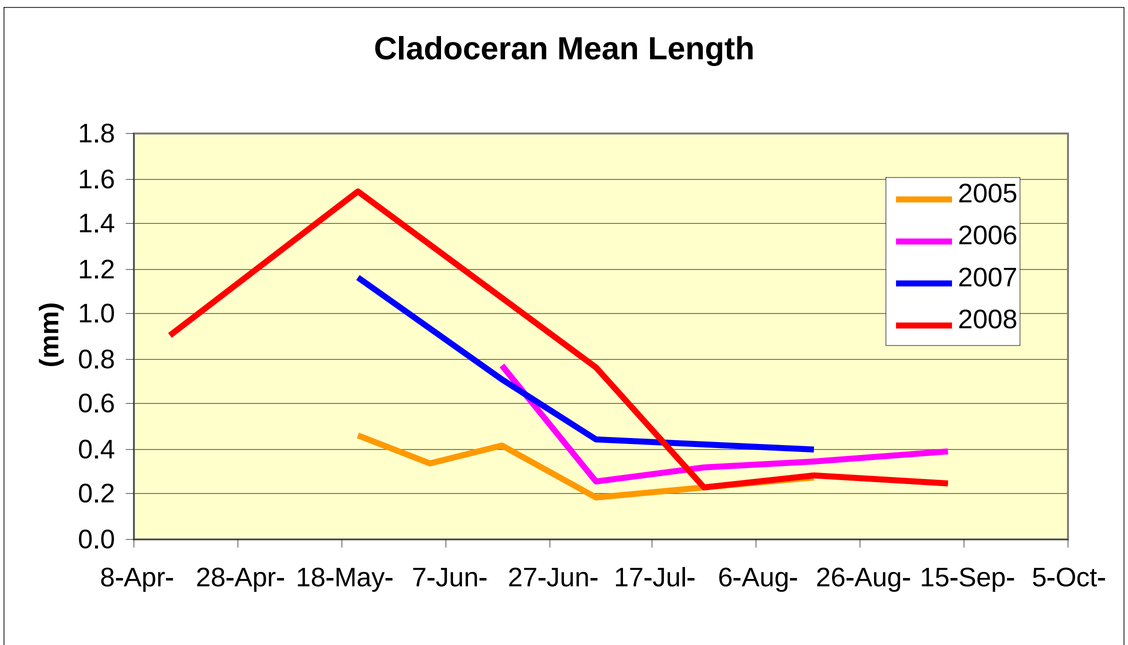


Figure 19. Length of Cladoceran taxa. *Daphnia* length in Lake Delavan are shown as a reference of a lake where large *Daphnia* were able to significantly reduce the amount of algae. This length was achieved in Silver Lake in 2008 prior to the flood.

dation. This change in the fish predation likely is not the result of the overtopping as the fish survey in October 2008 did not find any additional fish that were not previously in the lake. The increase in fish predation is likely from the very successful natural reproduction of perch and to a lesser extent, bluegills. Part of the restoration techniques used in this lake were to maintain a large bodied zooplankton community which would help reduce algal levels, even if phosphorus concentrations were elevated. It appears this part of the restoration effort has been limited since the size distribution of the zooplankton community shifted to smaller forms in the second half of the summer of 2008.

Fish Community

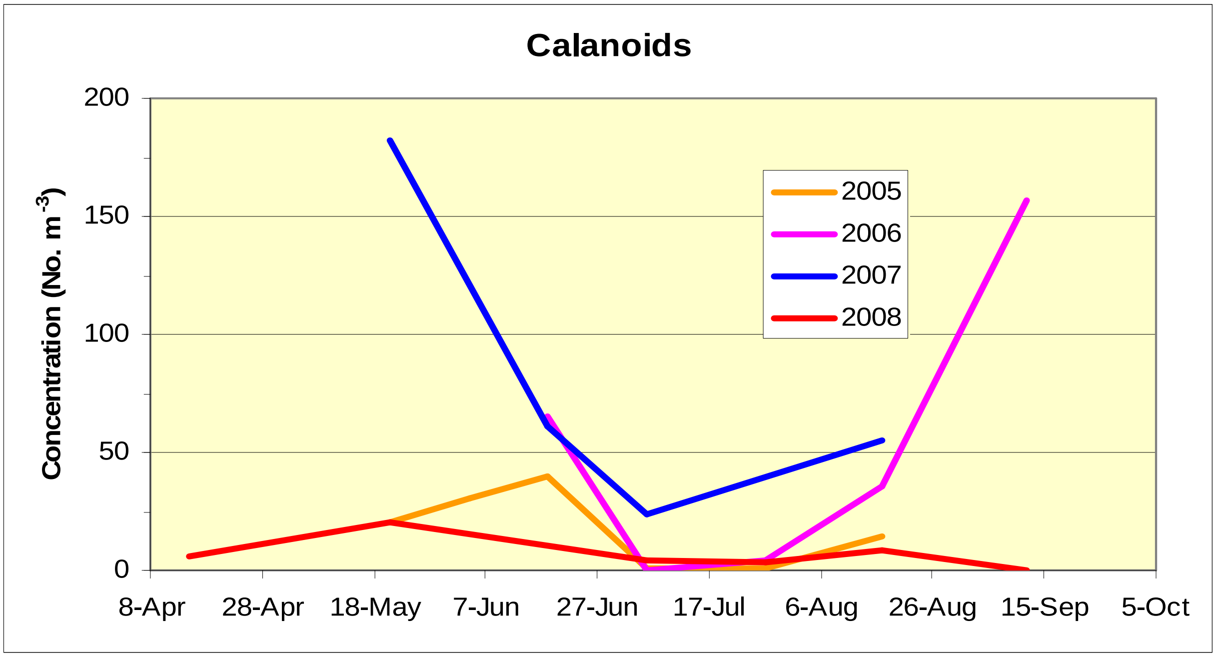
Following the fish eradication in the fall of 2003 a variety of fish species have been stocked in the lake. Through 2008, six species and over 180,000 individual fish have been stocked (Table 2). In general most of the stocked fish are doing well. The fish community has been sampled each fall since 2004 using a standard electrofishing boat. The entire shoreline is shocked at night and an attempt is made to net all fish, however, abundant young yellow perch has necessitated netting only a representative sample of perch.

Since 2004 CPE (catch per mile) has increased each year with the exception of 2006 when poor weather conditions made shocking difficult (Figure 21). Early in the time period gamefish, mainly largemouth bass and walleye, dominated the catch. However, since 2006 panfish, chiefly bluegill then yellow perch have dominated the netted catch.

Catch rates and average lengths have improved each year for most species. The most abundant species in 2007 were bluegill and yellow perch. Largemouth bass numbers are relatively low and it appears there is limited natural reproduction. Northern pike are doing well and have exhibited good growth. A number of these fish have been harvested through the ice. Walleye are doing well but there is little evidence of natural reproduction. The complete report of about the sampling of the fish community in 2008 is found in Appendix B.

In addition to the fish netted, field notes indicate that since 2006 many thousands of yellow perch have been observed during electrofishing but not netted. It is likely since that year, yellow perch has been the dominant fish species in the lake.

Largemouth bass number in Silver Lake continues to be low. The total number of bass captured during each survey has changed little since 2006. Northern pike appear to be doing well in the lake and have exhibited very good growth. Walleye survival and growth appears to be good although additional stocking may be needed to maintain their abundance in the future.



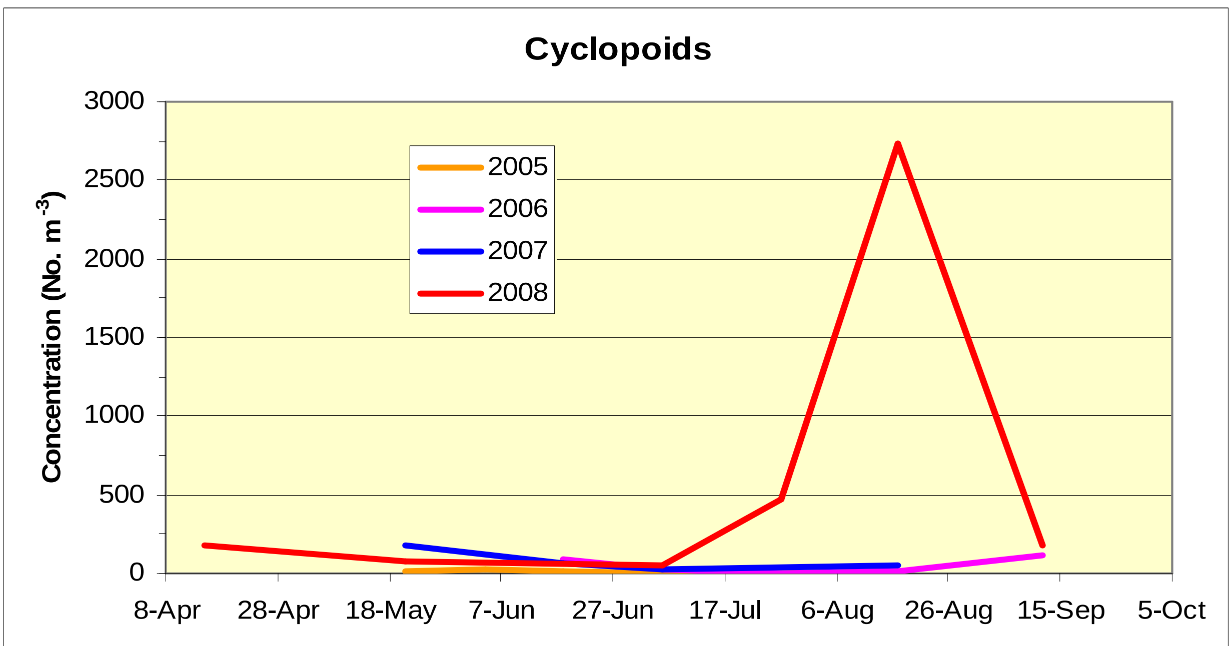


Figure 20. Copepods in Silver Lake after the completion of the restoration steps. The increased levels of the herbivorous Calanoids in the 2006 and 2007 are considered good they help reduce the amount of algae. Although the cyclopoid that was dominant following the flood in 2008 is herbivorous, *Tropocyclops prasinus* are small in size and thus do not consume large amounts of algae.

Panfish, chiefly yellow perch and bluegill, are reproducing and are abundant in number. Bluegill average length has steadily improved since 2004. Yellow perch average length which had shown little improvement between survey years because of huge year classes of perch that were competing for limited food resources showed some improvement in 2008.

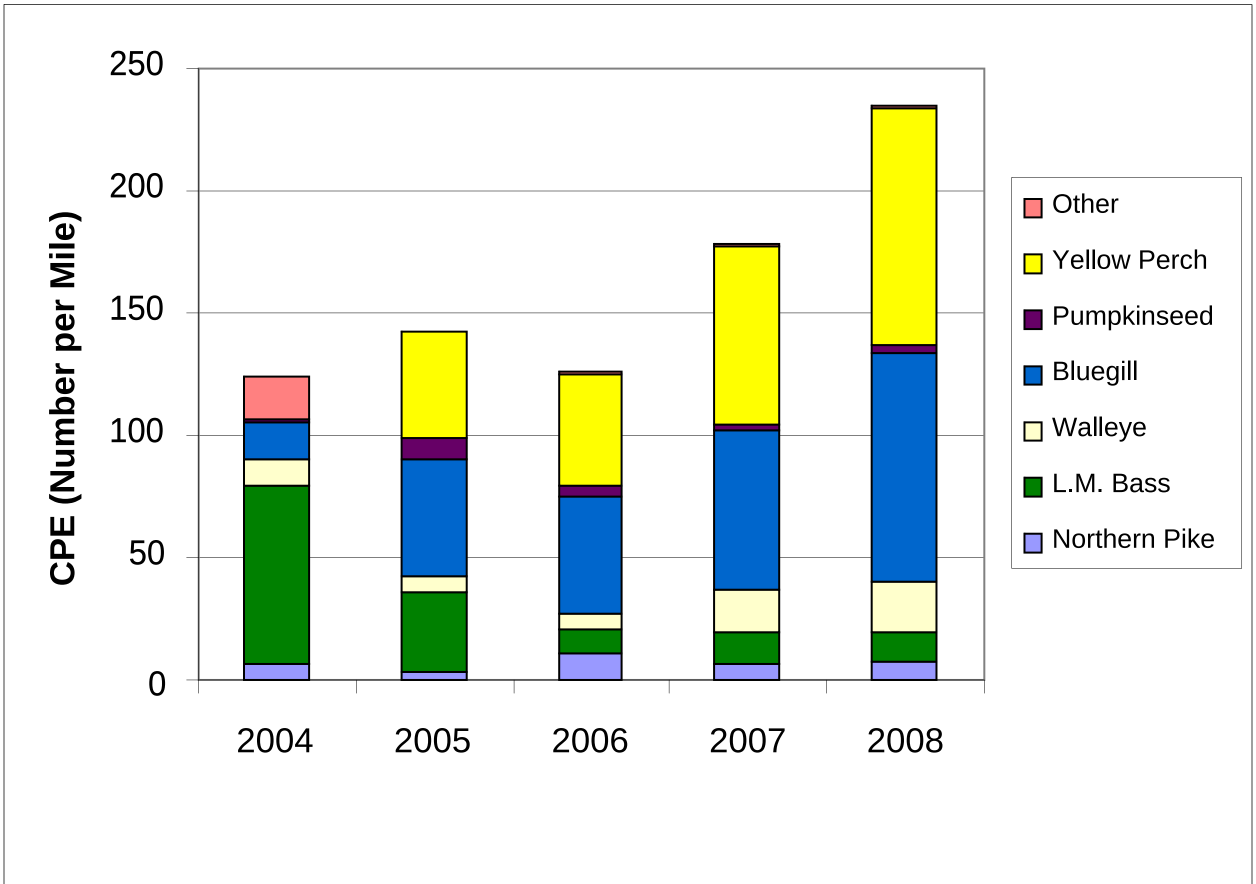


Figure 21. Catch per effort (CPE) trends of fish captured during the annual fall electrofishing assessment on Silver Lake.

There is some concern about the lack of forage species captured or observed in Silver Lake since 2006. White sucker abundance has decreased since 2004 and it appears that reproduction has been limited. Fathead minnow have not been captured during the survey since 2005. Their abundance may have been reduced by predation. Since these species appear to be scarce, it is likely that small yellow perch are being utilized as forage by predators.

Undesirable species, carp, bullhead and alewife have been captured in the lake in periodically since 2004 but in lower number. A few alewife were noted in the lake in 2004. These fish are highly undesirable as their primary diet are zooplankton. Consequently their presence would greatly reduce the size of the zooplankters and thus the ability of the zooplankton to reduce the amount of algae present in the lake. Since nearshore fall electrofishing sampling is not the best method of collecting alewives because these fish are primarily found in the open water of the lake, another method was needed to determine if alewife had reestablished themselves in the lake. In July 2006, Dr. Thomas Hrabik conducted a detailed survey of the lake using gillnets and hydroacoustic gear. His study confirmed the absence of alewives but did find that the dominant fish in the pelagic area was black bullheads. The complete report on this study is found in Appendix C. Since this study, alewife have not found in the lake.

It is hoped that this trend will continue and that any undesirable species found in the lake will remain low in abundance. The complete report of about the sampling of the fish community in 2008 is found in Appendix B.

A few alewife were noted in the lake in 2004. These fish are highly undesirable as their primary diet are zooplankton. Consequently their presence would greatly reduce the size of the zooplankters and thus the ability of the zooplankton to reduce the amount of algae present in the lake. Alewives were not found in succeeding years. The fall electrofishing sampling is not the best method of collecting alewives because these fish are primarily found in the open water of the lake while electrofishing is done close to the lakeshore. In July 2006, Dr. Thomas Hrabik conducted a detailed survey of the lake using gillnets and acoustical techniques. This study confirmed the absence of alewives but did find that the dominant fish in the pelagic area was black bullheads. The complete report on this study is found in Appendix C.

Trophic State Index

The concept of trophic status is based on the fact that changes in nutrient levels (phosphorus) causes changes in algal biomass (chlorophyll *a*) which in turn causes changes in lake clarity (Secchi disk transparency). A trophic state index (TSI) is a convenient way to quantify this relationship. Theoretically the TSI should be similar for all three measurements. If they differ this indicates that conditions in the lake are not balanced. Following the eradication of the fish community, it was hoped that the fish community would minimally feed on the zooplankton community. Towards this end, planktivores, such as black crappies, were not introduced into the lake. It was hoped that by having a low ratio of planktivores to piscivores, the zooplankton community would reduce the size of the algal community beyond what would be expected at the phosphorus concentration found in the lake.

Figure 22 shows the three trophic state indices for the years 2003-08. For the years 2003-06 the TSI for phosphorus and chlorophyll were similar in both basins. This indicates that the biomanipulation that was hoped for from the zooplankton was not successful. In 2007 both Secchi and chlorophyll were better than for phosphorus indicating that the biomanipulation may be starting to take effect. In 2007 the zooplankton community was larger and more numerous than in previous years. This may be due to the change in the structure of the fish community with less planktivores being present. Another reason for the improvement may be the increase in the amount of macrophytes. These plants provide some protection for the zooplankters from fish predation. In 2008 the summer mean TSI values for chlorophyll and Secchi was better than those for phosphorus indicating that less phosphorus was going into algal biomass than would be expected. This is another sign that the biomanipulation is working.

This is unexpected as the zooplankton community size structure was small after mid-June. In fact the mean length of cladocerans was as small as it was in 2005 (Figure 19). Although the summer mean TSI for 2008 indicates that the biomanipulation is working this is an artifact of the high success of the biomanipulation prior to the flood. Figure 23 shows that after mid-July that the trophic variables had similar TSI values until early September when chlorophyll concentrations were less than expected.

Discussion

Silver Lake responded well to the restoration effort that was performed on the lake. The stream diversion had significant impact on reducing the phosphorus levels in the lake. Phosphorus levels were reduced from over 200 to 100 µg L^{-1}. These levels were still unacceptably high so a fish eradication was performed and the lake treated with alum to reduce the internal loading of phosphorus. These efforts were also successful with phosphorus concentrations being further reduced to below 30 µg L^{-1} through 2007. Algal levels were similarly reduced and water clarity also improved. Part of the restoration effort was structuring of the fish community to reduce predation on the zooplankton community to allow it to reduce algal levels below what would be expected, given the phosphorus concentration. The zooplankton community was slow to respond but by 2007 was present throughout most of the summer although they were not as large as was desired. In 2008 it appeared success was finally achieved. Very high numbers were present during the first part of the summer and the mean body length was over 1 mm. This all changed after the stream overtopped its banks in June 2008. The size structure of the zooplankton community became small and *Daphnia* were not present the rest of the summer.

To date, establishment of a desirable, self-reproducing fish community has gone well. Stocking and conservative fishing regulations have contributed towards the restoration of a popular fishery. Despite the limited availability largemouth bass, northern pike and bluntnose minnow caused by shifts in State hatchery production, the moratorium on field transfers of fish because of Viral Hemorrhagic Septicemia (VHS) and the illegal stocking of panfish, the fish population of Silver Lake continues to improve. Since gamefish have delayed maturity, natural reproduction has been limited by the number of fish of spawning age. Panfish, mainly yellow perch and bluegill, have rapidly increased in number through reproduction. High numbers of small yellow perch can be both a benefit and a negative to the lake ecosystem. On the positive side, small perch can be used as a source of forage by predator fish when minnow species are lacking as is the case in Silver Lake. But on the negative side, young yellow perch can be highly planktivorous and may selectively feed on large zooplankton. Although it is perhaps too early to decide if the Silver Lake Restoration Plan for a predator heavy community has been met, anglers utilizing the lake are happy with the progress to date. Time will tell if gamefish reproduction will increase enough to keep panfish numbers in check or if changes in regulation or further predator

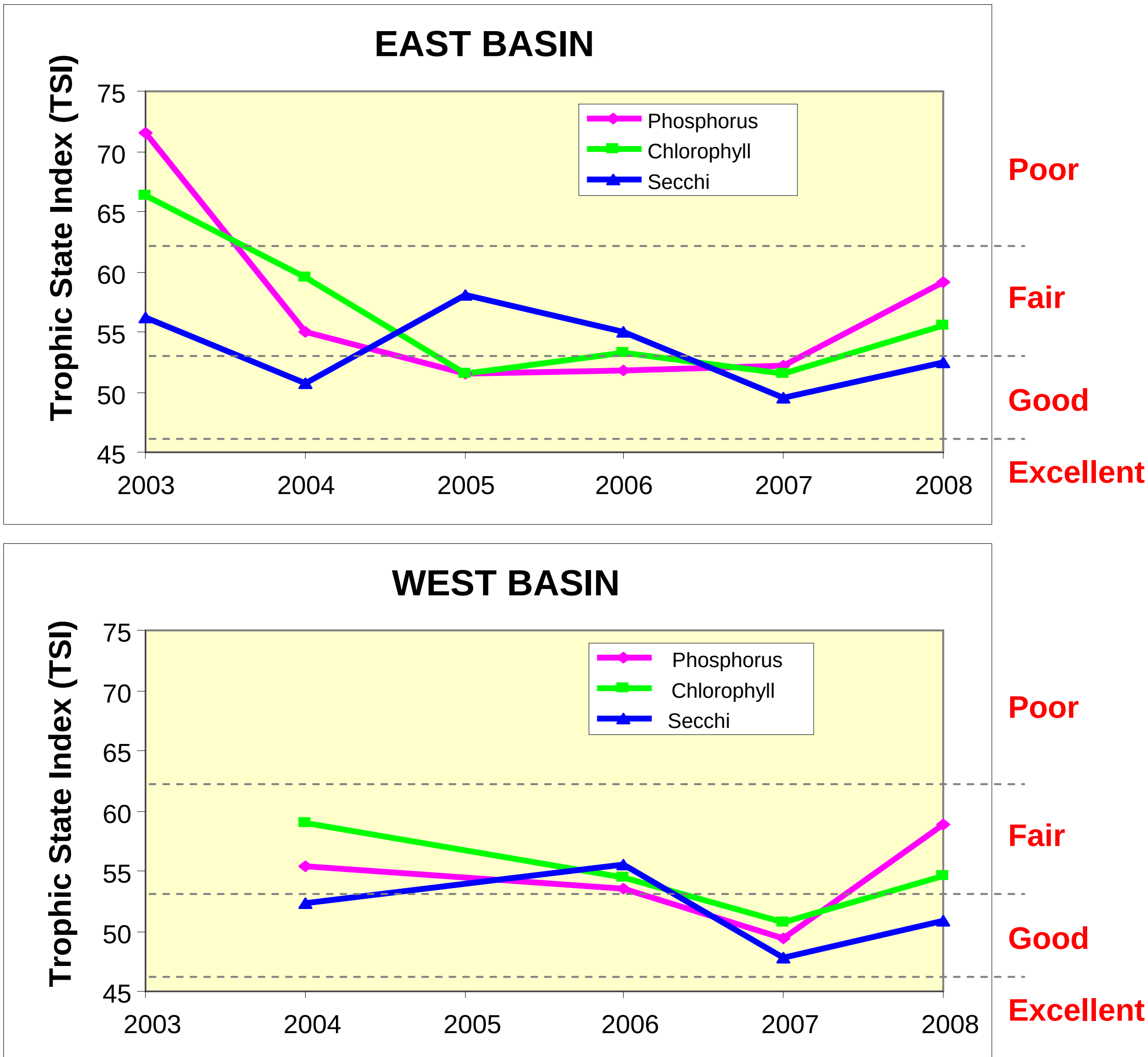


Figure 22. Trophic State Index (TSI) for Silver Lake for the years 2003-08. Since 2004 when the restoration work was completed, the TSI has been in the good to fair category. The TSI increased some in 2008 in response to the flooding.

stocking will be necessary to achieve restoration goals.

The one part of the lake ecosystem that has not responded to date as hoped is the macrophyte community. Plants have been slow to become established and their diversity is low. Compared with other lakes in the same ecoregion, the macrophyte community of Silver Lake has a poorer condition than these lakes (Figure 24). It is not clear why this community has not responded as hoped. It may be that this lake was abused for such a long time period that sediment conditions are not conducive for plant growth and there may be a very low seed bank.

Impact of stream flooding in June 2008

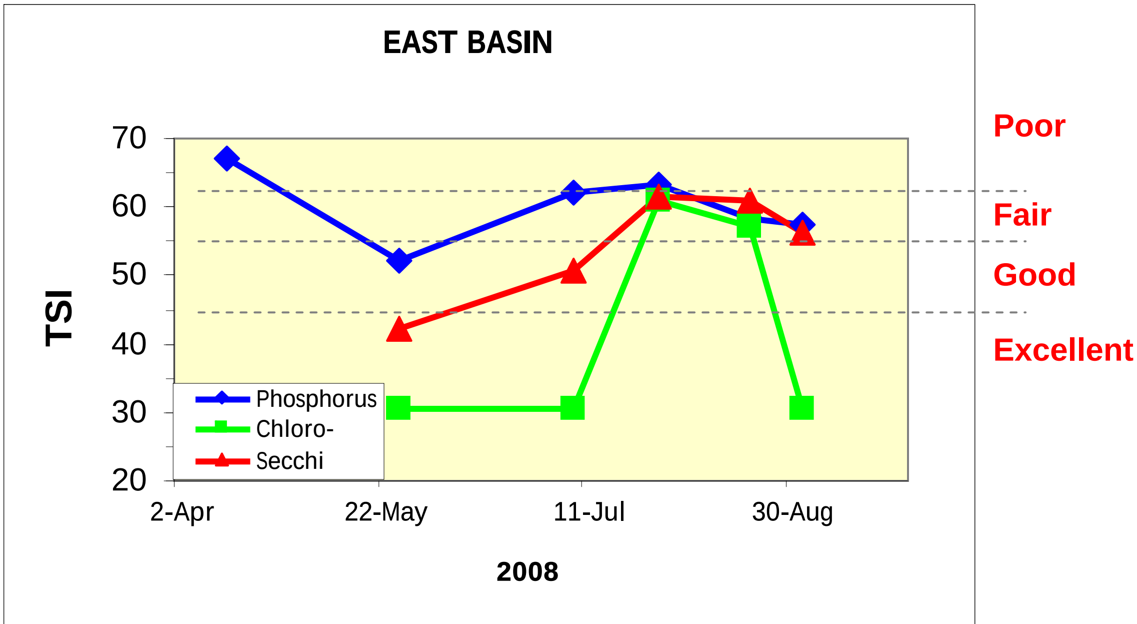


Figure 23. TSI values for the East Basin in 2008. Values increased after the flooding in June moving the lake condition from good to fair.

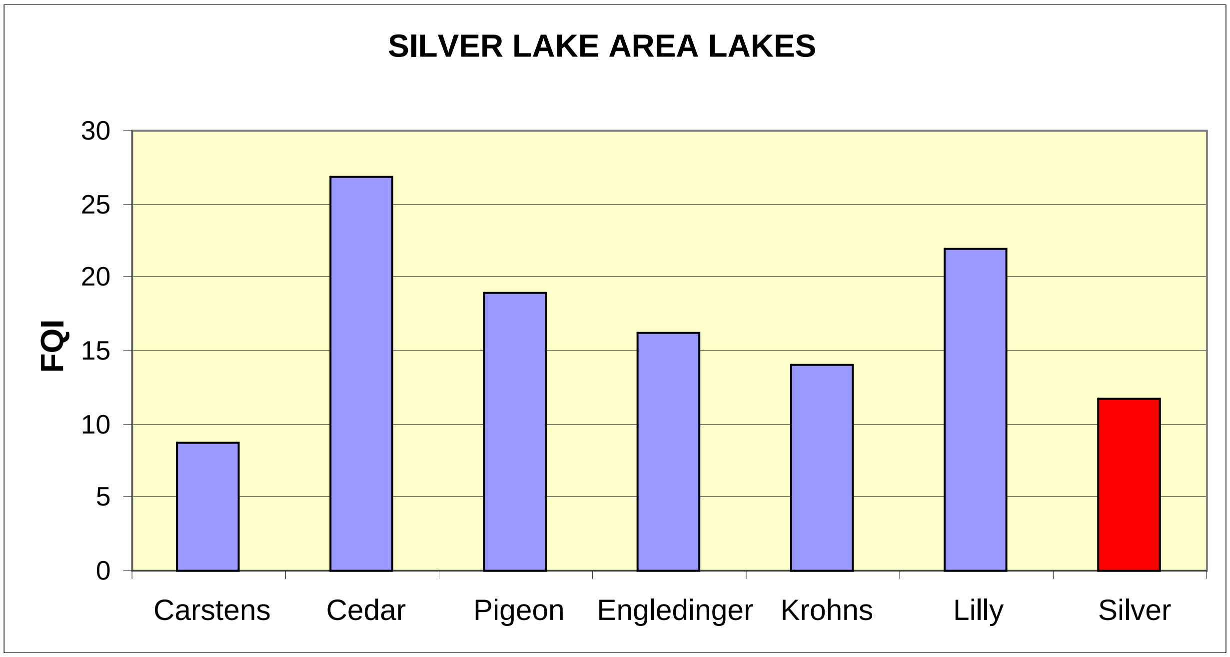
In June 2008 part of Wisconsin, including the area around Silver Lake, experienced an unusually high amount of rainfall. This resulted in much flooding in the area, including Silver Creek. For a few days a significant amount of flow from Silver Creek discharged into the lake (Figure 12). This had happened for a few hours in 2004 and 2007, but much more water entered the lake in 2008. In fact, the lake level increased over 3 feet, implying that over 280,000 m^3 or 74 million gallons of water entered the lake from Silver Creek and overland flow. What was the impact of this on the restoration efforts of the lake?

Phosphorus and other trophic variables were higher the rest of the summer compared to the years 2004-07. However the levels of all three variables was better than prior to fish eradication and alum treatment (2003). The input from the stream may have had a more significant impact on the internal loading of phosphorus from the deep water sediments. While phosphorus levels in the bottom waters were much higher in 2008 than they had been since the alum treatment they were not as high as in 2003. It appears the high sediment load from the stream may have buried the alum layer and reduced its effectiveness. This would mean the lifespan of the treatment will be much less than was originally hoped.

While the flooding of Silver Creek had an adverse impact on Silver Lake, it did not destroy all of the restoration efforts. The biomanipulation part of the effort may have been negated and the life span of the alum treatment may have been shortened but the external loading is still much less than it was prior to the diversion. Even though phosphorus levels were elevated in 2008, they are still much lower than they were prior to 2004.

Use Assessment

Silver Lake is presently on the 303(d) list of impaired waters because of elevated total phosphorus



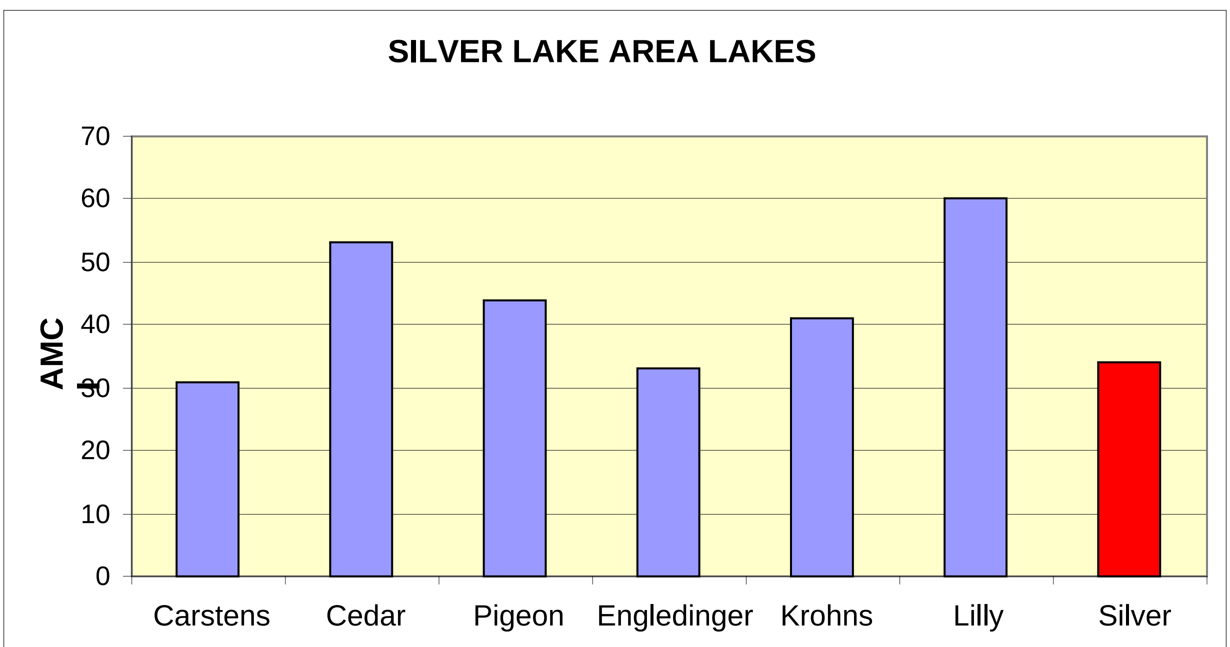


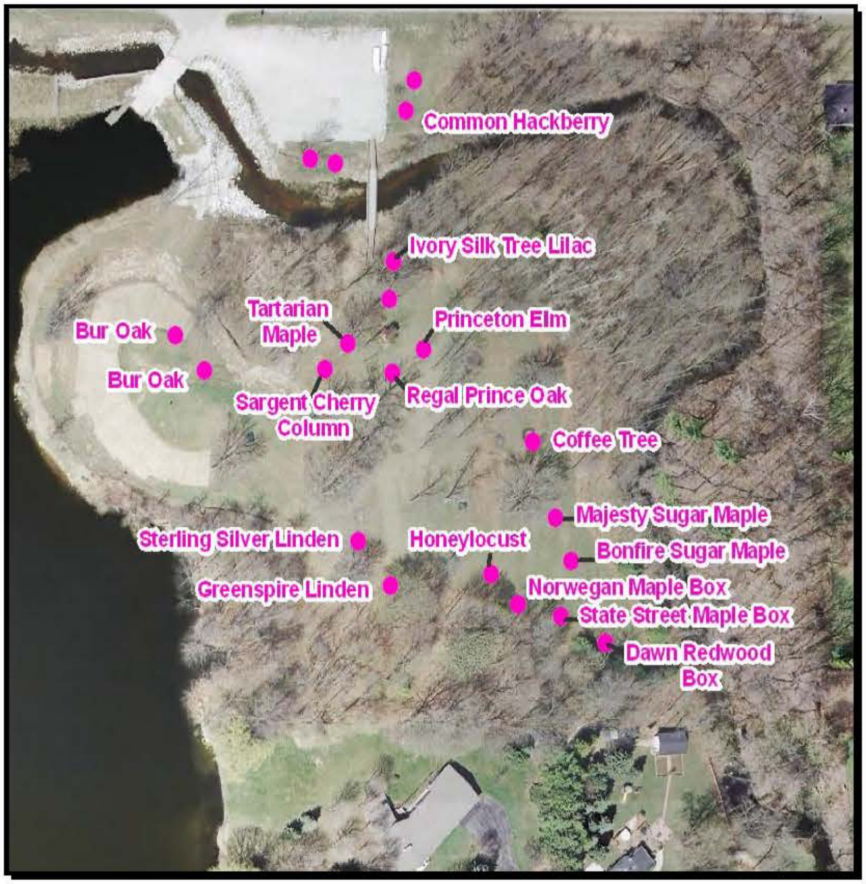
Figure 24. Comparison of macrophyte metrics in Silver Lake with other lakes in the same Lake Michigan Lacustrine Clay Plain Ecoregion. Higher numbers indicate better community condition. In Silver Lake the macrophyte community is in poorer condition than most of the other lakes.

concentrations. Using the proposed Guidance for the Classification, Assessment, and Management of the Surface Waters of Wisconsin, Silver Lake's use assessment was classified as poor since the TSI_{chl} based on 1996 data was 74. In 2008 its TSI_{chl} was 53 (Figure 22) which puts the lake on the cusp between good and fair. This improvement in use attainment makes the lake a good candidate for removal from the 303(d) list.

Although TSI values are good, the macrophyte community has not responded as expected. Although use assessment based upon the macrophyte community has not been established, the low metric values of FQI and AMCI probably would place Silver Lake in the poor condition. There is not sufficient plant data prior to 2000 but it is likely that the current plant community is better because of the greater water clarity.

Perhaps one of the best indicators of the improvement of the lake ecosystem is the significant increase of the lake and the county park on the lakeshore. Since the completion of the inlake restoration efforts, there has been are large increase in fishing pressure on the lake, both from boaters and fishermen along the lakeshore. On most weekends the parking lot is full. Because the improved use assessment of the lake, the county park is also being improved. The upgrading of the park involves a large number of improvements. These include a redesign of the landscape of the park and a new bridge across Silver Creek (Figure 25). There have been significant landscaping improvements including removal of old and diseased trees and replacement with a more diverse herbaceous community, establishment of a prairie, removal of terrestrial exotics, e.g. honeysuckle and buckthorn, and establishment of a rain garden (Figure 26). Footpaths with sitting benches, a pavilion, gazebo, shoreline restoration through a DNR grant, seven educational signs and two fishing piers have also been placed in the park (Figure 27). Park usage has returned to levels not experienced for several decades and it has become a popular designation for families and other nearby residents.

Figure 25. Aerial photo and drawing of the county park on Silver Lake. Also shown is the new bridge over that spans Silver Creek. The bridge can be seen in the upper part of the aerial photo.



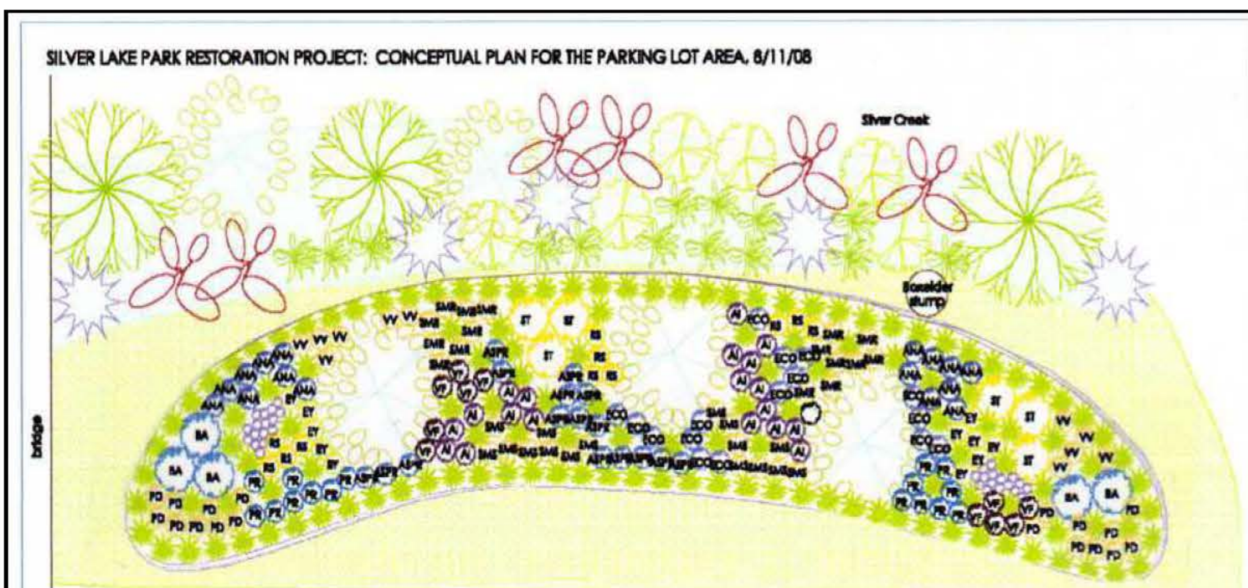


Figure 26. Top: aerial photo of the park indicating some of the new plantings. Below: schematic of rain garden that will be placed next to the parking lot.

Figure 27. Top: fishing pier on the shoreline of the County Park. Bottom: the gazebo placed on a knoll in the center of the park.

APPENDIX A. 2008 MACROPHYTE SURVEY

2008 Silver Lake Aquatic Plant Survey Results

Prepared by Mary Gansberg

<u>Silver Lake, Manitowoc County, Waterbody ID Code 67400.</u>

Aquatic macrophyte (plants) surveys were conducted by the Wisconsin Department of Natural Resources (WDNR) on Silver Lake in Manitowoc County in 1979, 2004, 2005, 2006, 2007, and 2008 to assess the overall aquatic plant community present in the lake.

This report summarizes the 2008 aquatic plant survey results and compares the results to previous surveys. The 2008 survey was conducted on August 21 by Mary Gansberg of the WDNR and Dr. Erik Hoyer from Silver Lake College. Survey methods and locations followed the 2005, 2006 and 2007 surveys.

Chara, leafy pondweed, and spatterdock continue to be the three most abundant macrophyte species found in Silver Lake; however the frequency of occurrence of these species is still extremely low as shown in the table below. Leafy pondweed appears to have expanded slightly from six sites in 2007 to 10 sites in 2008.

Unfortunately, Eurasian watermilfoil (Myriophyllum spicatum) was found in Silver Lake for the first time. One small rooted colony (approximately 1-foot by 2-feet) was found at the end of the boat launch pier. The entire colony, roots and all, were hand pulled and removed from the lake.

Species	**2005**	**2006**	**2007**	**2008**
Chara	1 site	9 sites	12 sites	11 sites
Leafy pondweed	3 sites	3 site	6 sites	10 sites
Spatterdock	3 sites	1 site	3 sites	1 site

Filamentous algae decreased slightly from previous years. In 2006, filamentous algae were found at 56 sampling sites. In 2007 it was found at 82 sites, but in 2008, filamentous algae were only present at 31 sites.

The number of <u>submergent</u> aquatic plant species (species richness) in the lake remains the same. Unfortunately, small bladderwort and sago pondweed were not found during the 2008 survey. Maximum depth of plant growth in 2006 was 9-feet. In 2007, maximum depth of plant growth increased to 11.5 feet, but in 2008 it was down to only 8.4 feet.

Percentage of the littoral zone with plants was 13.3 percent (excluding filamentous algae) in 2006. In 2007, it was 20.9 percent. In 2008 it was 18.2 percent. These numbers are very low considering most lakes in this area are in the 60-80 percent range.

Overall, the frequency and diversity of aquatic vegetation is still severely limited in Silver Lake. The presence of Eurasian watermilfoil is of particular concern and needs to be watch carefully.

	2004	**2005**	**2006**	**2007**	**2008**
Number of submergent species observed	2	2	3 (includes 1 visual; sago pondweed)	4 (includes 1 visual; small bladderwort)	4 (includes 2 visuals; Vallisneria and EWM

Silver Lake 2008 Aquatic Plant Species List

Common Name	Scientific Name
Muskgrass	Chara sp.
Leafy pondweed	Potamogeton foliosus
Spatterdock	Nuphar variegate
Filamentous algae	Unknown species
Swamp loosestrife	Decodon verticillatus
Hardstem bulrush	Schoenoplectus acutus
Wild celery	Vallisneria americana
Duckweed	Lemna minor
Cattail	Typha sp.
Water smartweed	Polygonum amphibium
Pickerelweed	Pontederia cordata
Eurasian watermilfoil	Myriophyllum spicatum

Silver Lake 1979-2008 Aquatic Plant Species Present

Common Name	1979	2004	2005*	2006	2007	2008
Muskgrass (Chara)			X	X	X	X
Leafy pondweed		X	X	X	X	X
Spatterdock	X	X	X	X	X	X
Filamentous algae			X	X	X	X
Swamp loosestrife				X	X	X
Hardstem bulrush	X		X	X	X	X
Wild celery					X	X
Duckweed					X	X
Cattail	X			X	X	X
Water smartweed				X		X
Pickerelweed						X
Eurasian watermilfoil						X
Small bladderwort (Utricularia minor)					X	
Iris				X		
Sago pondweed (Stuckenia pectinata)		X		X		
Common arrowhead (Sagittaria latifolia)				X		
Reed canary grass (Phalaris arundinacea)				X		
Sedges	X					

APPENDIX B. 2008 FISH SURVEY

CORRESPONDENCE/MEMORANDUM

State of Wisconsin

DATE: October 21, 2008 FILE REF:

TO: Silver Lake Files

FROM: Steve Hogler

SUBJECT: Fall 2008 Survey Results

On the night of October 20 the entire shoreline of Silver Lake was electrofished to assess the fish community of the lake. The 2008 survey repeated similar surveys that were conducted the four previous falls following the fall 2003 rotenone treatment and the subsequent restocking of fish into the lake.

Since the fall 2003 rotenone treatment, Silver Lake has been stocked with a variety of fish species that should result in self-sustaining populations, be desired by anglers and help to maintain the water quality goals of the restoration project. To date, six species and over 191,000 individual fish have been stocked (Table 1).

Table 1. Fish stocked into Silver Lake since the 2003 rotenone treatment.

	2004	2005	2006	2007	2008	Total
Largemouth Bass	10,000 (small fingerling)	1,000 (small fingerling)	--	--	--	**11,000**
Walleye	1,000 (small fingerling)	1,400 (large fingerling)	1,360 (small fingerling)	1,358 (small fingerling)	1,358 (small fingerling)	**6,476**
Northern Pike	2,000 (small fingerling)	6,800 (small fingerling)	--	--	6,800 (small fingerling)	**15,600**
Northern Pike	100 (large fingerling)	--	3,000 (large fingerling)	--	--	**3,100**
Yellow Perch	4,000 (small fingerling)	1,000 (small fingerling)	--	--	--	**5,000**
Fathead Minnow	150,000 (adult)	--	--	--	--	**150,000**
White Sucker	250 (adult)	250 (adult)	322 (adult)	--	--	**822**
Total	**167,350**	**10,450**	**4,682**	**1,358**	**8,158**	**191,998**

In addition to the fish stocked by the State, several species of fish, most notably bluegill and pumpkinseed were found in the lake during surveys since 2004. It is suspected that these fish were illegally stocked into the lake following the rotenone treatment.

2008 RESULTS

587 individual fish representing ten species were captured during the 88 minutes of shocking. Total CPE was 399.3 fish per hour shocked or 266.8 fish per mile. Yellow perch and bluegill dominated the catch with fewer fish of other species captured (Table 2). In addition to the yellow perch that we

captured, many thousands were seen but not netted.

Walleye and largemouth bass were the most common gamefish captured although northern pike were also present but in lower number. However, this may be misleading because many northern pike were seen and not captured.

Table 2. Length frequency for each species captured on Silver Lake during the October 20 electrofishing survey.

Length (mm)	Northern Pike	Largemouth Bass	Walleye	Black Bullhead	Green Sunfish	Pumpkin-seed	Bluegill	Yellow Perch
50		1						
60				1				
70		2						21
80					1		4	42
90							2	7
100		3				1	2	
110					1	2	11	
120						1	2	2
130					1		10	9
140		1				1	31	38
150		1	1	1			31	36
160				1		1	49	27
170			2				44	16
180			1				16	7
190			2				4	3
200								3
210			2					1
220			2					1
230			4					
240		1	2					
250	1		3					
260		1						
270		2	1					
280		1						
290		1						
300	1							
310	1	1						
320		2						
330								
340	1							
350	1							
360			3					
370		1	1					
380		2						
390		1	1					
400		4						
410		1	1					
420								
430		1	1					
440								
450			3					
460			2					
470			2					
480			3					
490			3					
500								
510								
520	1		1					
530								
540								
550								
560			1					
570			1					
580								
590	1							
600								
610	1							
620								
630								
640	1							
650	1							
660	1							
670	2							
680								
690	2							
700								
710								
720	2							
Total	17	27	43	3	3	6	207	213
Ave. Length	556	275	348	127	111	127	156	133
S.D.	168.42	127.06	129.13	54.84	25.24	22.34	22.35	38.75

Gamefish

The 43 walleye that we captured ranged in length from 153 mm to 575 mm and had an average length of 348 mm (Table 2). Thirteen of the forty-three (30.2%) captured walleye were greater in length than the 18” size limit on the lake. The average length of netted walleye in 2008 increased from those seen in previous years and likely reflects normal growth with increasing age. It also appears that representatives from each of the five stocked year classes were captured during the survey. Walleye were captured with a CPE of 29.2 per hour or 19.5 per mile shocked.

Largemouth bass were also commonly captured during the survey. The 27 bass that we captured ranged in length from 59 mm to 437 mm and had an average length of 275 mm (Table 2). Average length in 2008 was 25 mm greater than what was measured in 2007. As was the case the previous two falls, a low number of young of year (yoy) bass were captured in 2008. It is likely that bass reproduction is limited by the low number of bass of spawning age. CPE for bass was 18.4 fish per hour or 11.9 per mile shocked.

The seventeen measured northern pike ranged in length from 256 mm to 720 mm and had an average length of 556 mm (Table 2). Growth appears to be good, with 41.1% (7 of 17) of the captured pike larger than the 26” minimum size limit for pike in the lake. However, the lack of young fish may indicate poor reproduction by pike in the lake.

Panfish

Yellow perch were the co-dominant panfish captured in 2008, but since field notes indicate that thousands of small yellow perch were observed but not captured it is likely that yellow perch continues to be the dominant species of fish in the lake (Table 2). Yellow perch length ranged from 70 mm to 221 mm with perch having an average length 133 mm. Most yellow perch had lengths clustered either around 80 mm or 150 mm. It is likely that the captured yellow perch that were clustered around 80 mm were young-of-year fish. CPE for captured yellow perch was 144.9 per hour or 96.8 per mile.

The 2008 average length of bluegill was 156 mm with lengths ranging from 88 mm to 197 mm (Table 2). It is likely several year classes were present in the sample including young-of-year bluegill. Bluegill CPE was 141.8 per hour or 94.1 per mile shocked.

Other captured panfish included green sunfish and pumpkinseed sunfish with average lengths of 111 mm and 127 mm respectively.

Other Species

During the survey we also captured several additional species of interest. These species included one carp, three black bullhead, two white sucker and one golden shiner.

Discussion

It appears that in general most of the stocked fish are doing well in Silver Lake. Average lengths have improved from those measured in 2007, while catch rates (CPE) for most species declined slightly. However, bluegill CPE increased slightly over what was measured in 2007. Slower shocking speed and poorer water clarity (1 meter) likely contributed to the decline in CPE’s noted in 2008.

Largemouth bass number in Silver Lake continues to be low. The total number of bass captured during each survey has changed little since 2005. Natural reproduction is occurring in the lake, but at a low rate. However, more bass are reaching spawning size and the six yoy collected during this survey does indicate bass are surviving and beginning to spawn. The next several years will be critical in determining how successful bass will be in Silver Lake.

Northern pike appear to be doing well in the lake and have exhibited very good growth. We did not find any evidence of successful reproduction again this year. In 2007 and 2008 we captured northern pike longer than the 26” size minimum and anglers have been harvesting a number of legal size pike while ice fishing. If harvest remains high, it is likely that natural reproduction could be limited because of the lack of adult fish.

Walleye are doing well in Silver Lake. Survival and growth appears to be good. We did not find evidence of natural reproduction in the lake and additional stocking may be needed to maintain their abundance in the future.

Panfish, chiefly yellow perch and bluegill, are reproducing and are abundant in number. Bluegill average length has steadily improved since 2004. Yellow perch average length which had shown little improvement between survey years because of huge year classes of perch that were competing for limited food resources showed some improvement in 2008. Anglers have begun to harvest bluegill and perch, but in low numbers. It is hoped that the 10 fish bag limit will protect these populations and allow continued improvement in the size structure of panfish in the lake.

Undesirable species, carp, bullhead and alewife were captured in the lake in 2004. Only bullhead were captured in 2005, 2006 and 2007. In 2008 three bullhead and one carp were observed and captured. The carp likely entered the lake during an overtopping event in June 2008. The single carp that was netted was removed from the lake and no other carp were observed despite our efforts to find them. It is hoped that this trend will continue and that any undesirable species found in the lake will remain low in abundance.

There is some concern about the lack of forage species captured or observed in Silver Lake since 2006. White sucker abundance has decreased since 2004 and it appears that reproduction has been limited. Fathead minnow have not been captured during the survey since 2005. Their abundance may have been reduced by predation. Since these species appear to be scarce, it is likely that small yellow perch are being utilized as forage by predators.

APPENDIX C. 2006 HRABICK FISH REPORT

Acoustic assessment of Silver Lake pelagic fishes

by:

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Abstract

We designed and implemented a hydroacoustic and vertical gillnet assessment on Silver Lake during July 2006 to estimate the density and composition of pelagic prey fish. Approximately 5 km of hydroacoustic transects were sampled during the night of July 12 and predawn period of July 13. The composition, density and biomass of prey fishes were estimated for portion of the lake > 3 m in depth. In general, fish density was slightly higher in the eastern basin of the lake. Species composition in the open water included black bullhead (*Ameiurus melas*), golden shiner (*Notemigonus crysoleucas*), yellow perch (*Perca flavascens*) and bluegill (*Lepomis macrochirus*). In the western basin, the gillnet catch was composed of black bullhead (60%), golden shiner (20%) and bluegill (20%). In the eastern basin, the catch included black bullhead (73.2%), yellow perch (24.4%) and golden shiner (2.4%). Our estimate of fish density in each basin was dominated by black bullhead, although golden shiner, yellow perch and bluegill represented the primary open water planktivorous species. The number of planktivores (excluding bullhead) in the open water area in eastern basin was approximately 14,718 and 13,548 in the western basin. The total biomass of planktivores in the open water area of the eastern basin was approximately 213.35 kg with a biomass density of 23.5 kg/ha and 247.26 kg total biomass and a biomass density of 42.2 kg/ha for the western basin. The densities of planktivorous species in the lake are not exceedingly high and suggest that planktivory may not underlie the persisting low water clarity observed in the lake.

Introduction

Silver Lake in Manitowoc County, WI (T19N, R23E, Sections 33 and 34) is a eutrophic lake currently being managed to improve water quality and to enhance the fishery. The Silver Lake Restoration project was implemented to improve water clarity to increase macrophyte growth and enhance fish habitat. The steps in the mitigation process included: 1. the construction of a barrier to reroute Silver Creek, 2. rotenone treatments to eliminate the rough fish, 3. alum treatments to reduce the phosphorus levels in the lake and 4. the reintroduction of desired fish species. Each phase of the project has been initiated and changes have been observed in the lake. The phosphorus concentration in the lake currently falls within the objective levels of 20-80 ug/L, having decreased from much higher levels. The clarity of Silver Lake, however, is less than expected given recent trends in phosphorus concentration in the lake (S. Hogler pers. comm.). The consumption of plankton by planktivorous fishes may indirectly cause increases algal biomass and associated decreased water clarity in northern temperate lakes (Carpenter and Kitchell 1993). Thus, it is possible that an abundant planktivorous fish population may be contributing to the lower water clarity through cascading trophic interactions (Carpenter and Kitchell 1993). The objective of this project was to implement a hydroacoustic survey to quantify the abundance of open water planktivorous fishes that are potentially important drivers of water clarity in Silver Lake. We provide estimates of planktivorous fish density for each of two primary basins of Silver Lake. In addition, we summarize whole lake density estimates of the most abundant planktivore species and provide population and total biomass estimates. These findings are derived from hydroacoustic and vertical gillnet sampling conducted on July 12 and 13 of 2006. The estimates of density and population size may be used in future studies to assess the importance of planktivory in driving water clarity in the lake.

Materials and Methods

Survey Design, Limitations and Description:

The survey design attempted to systematically cover Silver Lake with the objective of uniformly covering the area of the lake > 3 m in depth. Our approach focused on obtaining samples from open water sections within the survey area (Figure 1).

The collection of survey data adhered to the agreement between the Wisconsin DNR and Dr. Thomas Hrabik and was completed within the timeframe indicated in the agreement. We used 120-kHz split beam acoustic systems to estimate pelagic fish target strength and fish density in each basin of the lake. We sampled approximately 5.03 km of transects using hydroacoustics. We deployed a spectrum of vertical gillnets (19, 32, 51 and 64 mm stretch mesh) in the deepest portions of each basin to identify the composition of open water fish species (Figure 1).

Transect locations, acoustic information and gillnet locations were geo-referenced using a global positioning system (GPS) system attached to the hydroacoustic unit. Raw acoustic data and gillnet information were saved on computer hard drives and later copied to compact disks for data processing and archiving. Calibrations of the echosounder were performed using a tungsten carbide reference sphere (Foote et al. 1987, Foote 1990). The speed of the vessel was approximately 2 knots while collecting hydroacoustic data.

The vertical gillnets were deployed from the surface to the bottom in each basin so as to allow the identification of any vertical stratification of fish species within the lake. Fish data from the gillnet collections were to be used for species identification and to refine target strength estimates which were then used in fish density computations. By using the hydroacoustic information along with the species composition from the gillnet catch, we derived estimates of density for the abundant open water fish species.

Data Analysis

Acoustic data were collected using Biosonics Visual Acquisition software. Data were analyzed using Echoview analysis software (v. 3.25.55, Sonardata Pty. Ltd 1995-2003). Data from each basin were processed identically using the following procedures.

Data Quality

Prior to analysis, it was necessary to manually edit each echogram to ensure that only true fish echoes were included in analysis. Each echogram was examined for acoustic "noise" not likely attributable to fish backscatter (e.g., electrical interference, surface wave disturbance). We identified no interferences from noise or wave disturbance. Additionally, the Echoview bottom detection function was used to exclude sound returned from the lake floor from echo integration and bottom echoes were identified by the algorithm throughout the survey area.

Echo Integration

Echo integration was used to calculate the total amount of sound backscattered across all transects. The minimum raw echo-strength threshold was –60 dB. These analyses provided the Nautical Area Scattering Coefficient (NASC - a measure of the average amount of sound reflected by fish per square nautical mile) for each transect.

Single Target Detection

Fish density is calculated using the expected size of an acoustic fish to scale the NASC values. The single target detection algorithm of Echoview uses a suite of parameters to define raw echoes as likely fish targets. The settings used for single target detection along all transects are shown in Table 1. Echo strength for each target identified is then corrected for sound attenuation due to depth and angle off axis, providing a true measure of the sound reflected. Target strength was estimated using data in the linear domain using the following equation:

$$\bar{TS} = 10\log_{10}\left(\frac{1}{N}\sum_{i=1}^{N}10^{\left(TS_i/10\right)}\right)$$

where:

$\bar{TS}$ *or* TS_{mean} is the mean target strength estimated for a given transect and TS_i is the target strength for single fish i.

From this, the average target strength (TS_{mean}) for each transect was calculated.

Fish Density Calculations

Results from echo integration and single target detection were used to calculate fish density for each transect using:

$$\text{Density } ({}^{fish}/_{ha}) = \frac{NASC}{4\pi \cdot 10^{(TSmean/10)} \cdot 343}$$

where NASC is the nautical area scattering coefficient ($m^2 \cdot n.mi^{-2}$), $4\pi \cdot 10^{(TSmean/10)}$ is the average backscattering cross-section of an acoustic target (m^2), and 343 is the number of hectares per square nautical mile.

The area of lake within our defined depth strata was used to calculate the total number of fish in the lake during the survey period. We estimated abundance of fish in each basin by multiplying acoustic density (fish/hectare) by the number of hectares in the survey area (> 3 m depth).

We estimated fish densities and 95% confidence intervals within each basin. To correct for autocorrelation, transects were divided into segments of sufficient length (200 m) to eliminate autocorrelation between adjacent segments. We used the statistics derived from non-autocorrelated segments to estimate the density and associated variance for each of the embayments. We spaced each of the transects such that we were unlikely to encounter the same fish and considered each segment an independent sample.

Results and Discussion

__Gillnet Catch Composition__

Vertical gillnets were set in both the eastern and the western basin (Figure 1). Species composition in the open water included black bullhead (*Ameiurus melas*), golden shiner (*Notemigonus crysoleucas*), yellow perch (*Perca flavescens*) and bluegill (*Lepomis macrochirus*). In the western basin, the gillnet catch was composed of black bullhead (60%), golden shiner (20%) and bluegill (20%) (Figure 2). In the eastern basin, the catch included black bullhead (73.2%), yellow perch (24.4%) and golden shiner (2.4%) (Figure 2). There was substantial overlap in the depth distribution of the fish species present, with most fish being captured between 1 m and 4 m depth (Figure 3). We therefore used the gillnet catch to allocate acoustic scattering to each species.

Size Composition

Black bullhead, the largest and most numerous species captured in the gillnets in each basin ranged from 154 mm – 220 mm in the north basin and 160 mm – 225 mm in the south basin (mean = 191 mm, standard deviation = 17.4 (north basin), mean = 191 mm, standard deviation = 17.3 (south basin)) (Figure 4). Bluegill were captured in only the western basin and ranged from 97 mm – 110 mm (mean = 101.7 mm, standard deviation = 5.7) (Figure 4). Yellow perch were captured only in the eastern basin and ranged from 100 mm – 120 mm (mean = 108.6 mm, standard deviation = 7.7) (Figure 4). Golden shiners in the north basin ranged from 115 mm – 116 mm (mean = 115.5, standard deviation = 0.7) in the eastern basin and 81 mm -140 mm in the western basin (mean = 118.7, standard deviation = 27.2) (Figure 4).

Hydroacoustic Estimates of Density and Biomass

The density of fish in the open water area (the area >3 m) was similar among basins. The density of all fish combined was approximately 6053 fish per hectare in the eastern basin and 5771 fish per hectare in the western basin (Table 2). When scaled to the total area of each basin > 3 m total depth (the area considered here to be open water and effectively sampled by the hydroacoustic methods), estimates of density (including bullhead) in each area indicate that there were approximately 54918 fish in the open water area in the eastern basin and 33871 in the western basin during the period of study. The number of planktivores (not including bullhead) in the open water area in eastern basin was approximately 14718 and 13548 in the western basin (Table 2). Given the estimates of size for each species, the total biomass of planktivores in the open water area of the eastern basin was approximately 213.35 kg with a biomass density of 23.5 kg/ha and 247.26 kg total biomass with a biomass density of 42.2 kg/ha in the western basin. When compared to other Wisconsin lakes, these values are well within the range of planktivorous fish biomass densities observed for clear water lakes in Wisconsin and similar to that observed in oligotrophic systems such as Crystal and Sparkling Lakes (Vilas Co. WI) (Figure 5).

This project represents an initial step in identifying the importance of planktivorous fishes in the management of Silver Lake. Our results show that the densities of planktivores are within the range to be expected for northern temperate lakes and that planktivory may not be a likely determinant of water clarity in Silver Lake at present. Our findings indicate that native planktivorous species are present in the lake and that alewife (*Alosa pseudoharengus*), despite being captured in the lake previously, were not abundant. This report provides the population estimates needed to initiate bioenergetics simulations to determine rates of planktivory relative to rates of plankton production. Such an analysis would provide a direct metric of the influence of planktivores on lower trophic levels. In addition, analyses of plankton size distributions and composition also may indicate whether planktivory is an important factor influencing the lower trophic levels in the lake. During our survey, we observed many carp surfacing in the shallow water areas of the lake. It is possible that the sediment resuspension by these exotics is associated with sediment re-suspension and decreased water clarity, although this is speculation. Our overall conclusion, however, is that the density of planktivores in the lake does not exceed what would be expected for a typical northern temperate lake and that an abundant alewife is not associated with the observed low water clarity.

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Table 1. Echoview single target detection parameter settings used for all hydroacoustic data collected in 2003 and 2004.

Parameter	Setting
TS Threshold (dB)	-55
Pulse Length Determination Level (dB)	6
Minimum Normalized Pulse Length	0.5
Maximum Normalized Pulse Length	2.0
Maximum Beam Compensation (dB)	6
Maximum Standard Deviation of Minor-Axis Angles (dB)	1.0
Maximum Standard Deviation of Major-Axis Angles (dB)	1.0

Table 2. Estimates of density, population size and biomass of open water fishes in Silver Lake, WI. Values in parentheses indicate 95% confidence intervals about the mean.

Basin	Fish Species	Density (#/ hectare)	Area >3 m (hectares)	Population estimate (n)	Total Biomass (kg)
Eastern	b.bullhead	4430.84 (1309.95)	9.07	40200 (11885)	4401.91 (1301.4)
Eastern	g. shiner	145.27 (42.94)	9.07	*1318* *(390)*	*22.40* *(6.6)*
Eastern	y. perch	1476.94 (436.65)	9.07	*13400* *(3962)*	*190.95* *(56.4)*
Basin Total		6053.07 (1789.55)		*14718 * (4351.32)	*213.35 * (63.07)
Western	b.bullhead	3462.80 (861.39)	5.87	20323 (5056)	3105.37 (772.4)
Western	g. shiner	1154.26 (287.13)	5.87	*6774* *(1685)*	*132.10* *(32.8)*
Western	bluegill	1154.26 (287.13)	5.87	*6774* *(1685)*	*115.16* *(28.6)*
Basin Total		5771.34 (1435.65)		*13548 * (3370.32)	*247.26 * (61.50)

* includes total estimates for planktivorous species only

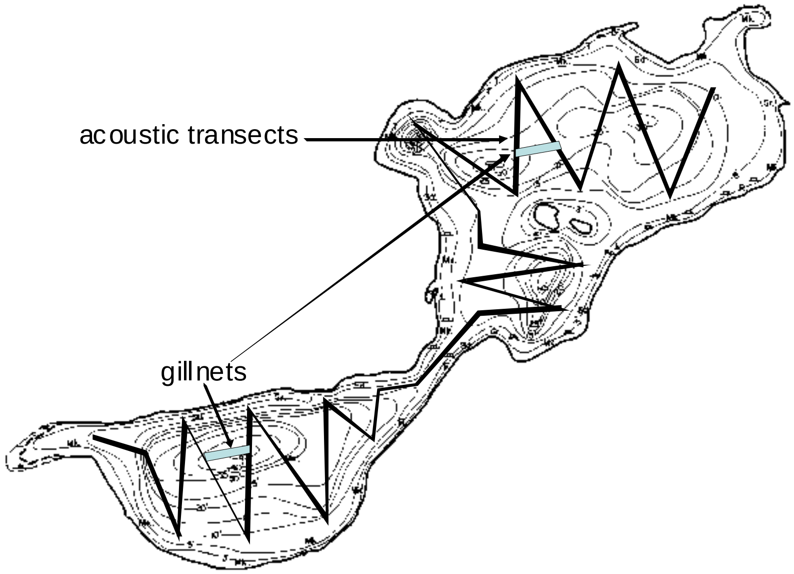

Figure 1. The location of hydroacoustic transects and vertical gillnets sets in Silver Lake, WI.

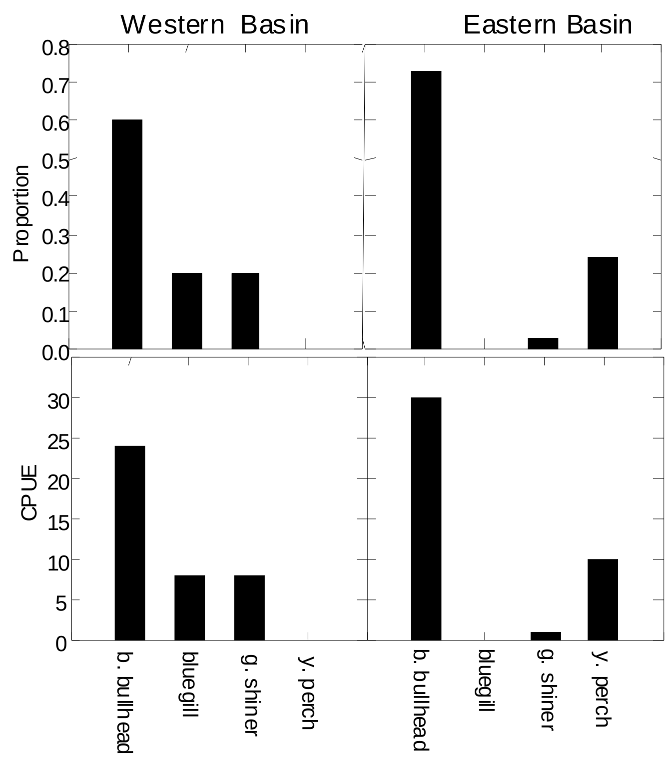

Figure 2. The catch per unit effort (#/6 hr. set) and proportion of catch of each abundant open water fish species.

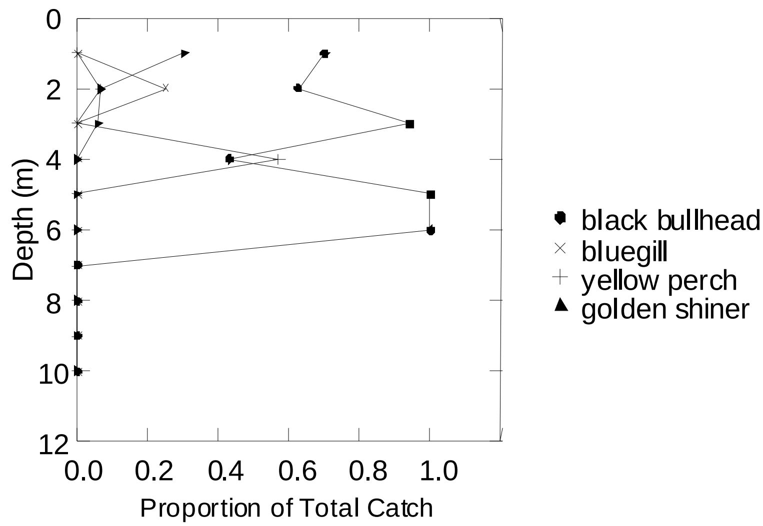

Figure 3. The proportion of the catch represented by each fish species at one meter depth intervals.

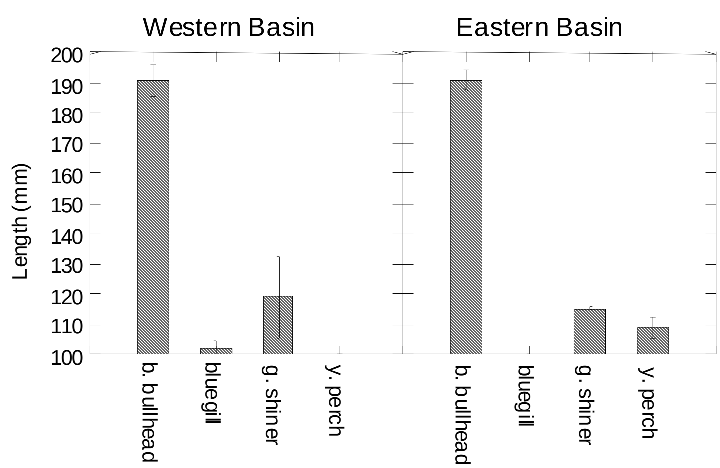

Figure 4. The mean sizes of each fish species captured in open water areas in Silver Lake, WI. Error bars represent one standard error of the mean.

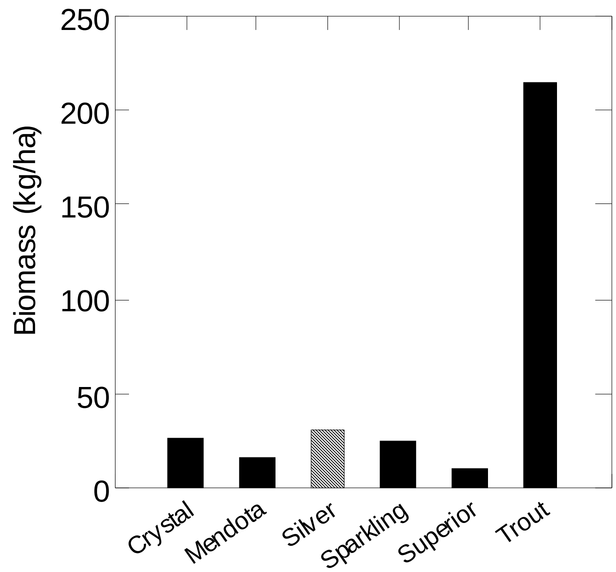

Figure 5. The biomass density estimated using hydroacoustics in various lakes. The hatched bar indicates Silver Lake.