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For:

Minnesota Pollution Control Agency

Bartlett Lake In-Lake Management Strategies

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Cover Image

Bartlett Lake from the August 21, 2014 Minnesota Biological Survey List of Plant Species Observed at Bartlett Lake by the Minnesota Department of Natural Resources.

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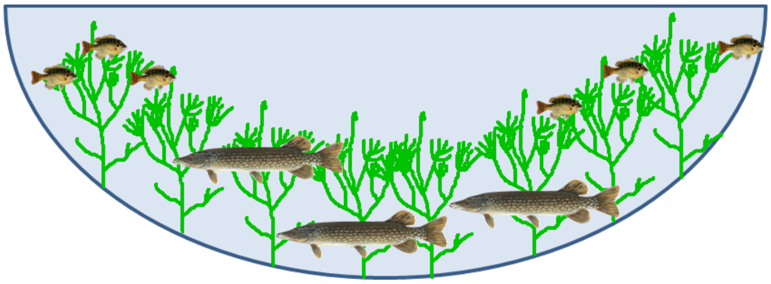
1. SHALLOW LAKE BIOLOGY AND WATER QUALITY

Lakes are considered shallow when most (>80%) of the lake area is less than 15 feet deep. Depths less than 15 feet are important biologically sunlight can penetrate to the lake bottom and support aquatic plant growth. In addition, all the living organisms in shallow lakes are concentrated in a smaller volume than in deeper lakes. Consequently, the relationship between phosphorus concentration and the amount of algae growth (measured by chlorophyll-*a* pigments and water transparency) is often different in shallow lakes as compared to deeper lakes. In deeper lakes, algae abundance is often controlled by physical and chemical factors such as light availability, temperature, and nutrient concentrations. The biological components of the lake (such as microbes, algae, aquatic plants, zooplankton and other invertebrates, and fish) are distributed throughout the lake, along the shoreline, and on the bottom sediments. In shallow lakes, the biological components are more concentrated into less volume and exert a stronger influence on the ecological interactions within the lake. There is a denser biological community at the bottom of shallow lakes than in deeper lakes because oxygen is replenished in the bottom waters and light can often penetrate to the bottom. These biological components can control the relationship between phosphorus and the response factors.

The result of this impact of biological components on the ecological interactions is that **shallow lakes normally exhibit one of two ecologically alternative stable states (Figure 1): the turbid water, algae-dominated state, and the clear water, aquatic plant-dominated state.** The clear state is the most preferred, since algae communities are held in check by diverse and healthy zooplankton and fish communities. In addition, rooted plants stabilize the sediments, lessening the amount of sediment stirred up by the wind.

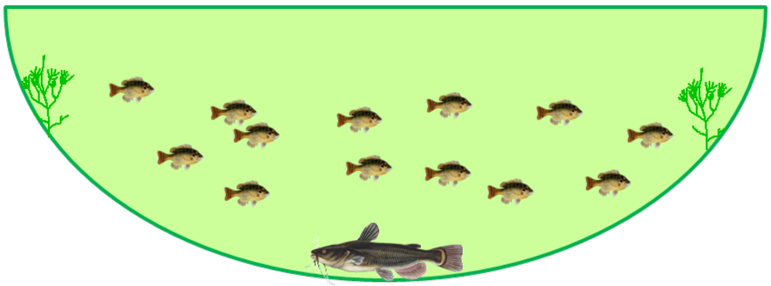
As shown in Figure 2, the transition in water quality of shallow lakes from clear to turbid is often abrupt. When shallow lakes have historically been in the clear water state and dominated by submerged aquatic vegetation, they are capable of assimilating large amounts of phosphorus loading without becoming dominated by algae. That is to say, they are stable in a clear-water state. They may experience some periods of turbid water conditions, but tend to revert to clear water conditions. However, as phosphorus loading increases, the stability of the clear-water state declines until the lake is stable in a turbid-water state. Consequently, drastic reductions in nutrients or changes in the biological community of a shallow lake are needed to promote a clear-water state (Figure 3).

It is important to note that Bartlett Lake has undergone extensive changes from human disturbances over a long period of time. Therefore, management of this lake should also be expected to be extensive and long-term. That is to say, continual management of shallow lakes is needed to maintain clear water. And it should be noted that a recent study comparing the characteristics of managed shallow lakes to those of other regional shallow lakes manifesting clear- or turbid- state conditions concluded that not all shallow lake rehabilitation efforts succeed and that when improvements occur, management may need to be repeated to maintain clear water in highly modified landscapes (Hanson et al. 2017).



CLEAR

Large fish (or the absence of all fish) and abundant rooted plants keep water clear.



TURBID

Too many panfish or too few rooted plants keep water turbid.

Figure 1. Alternative stable states in shallow lakes

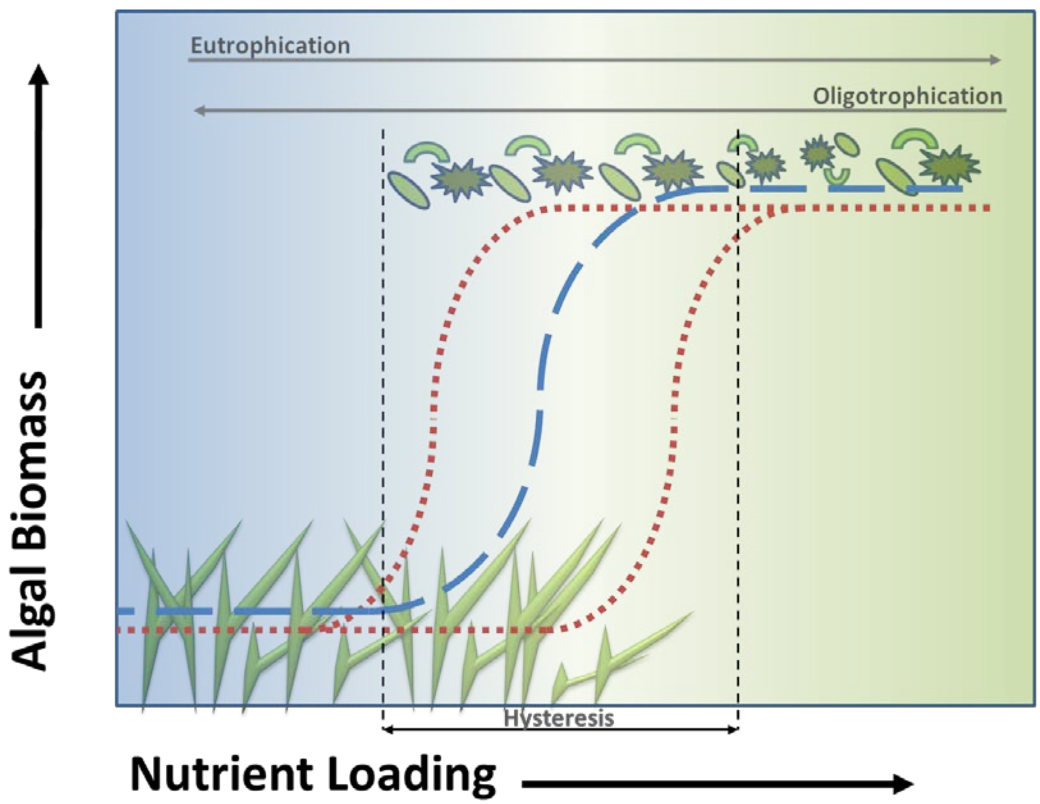


Figure 2. Trophic state shifts in shallow lakes in response to changes in nutrient loading

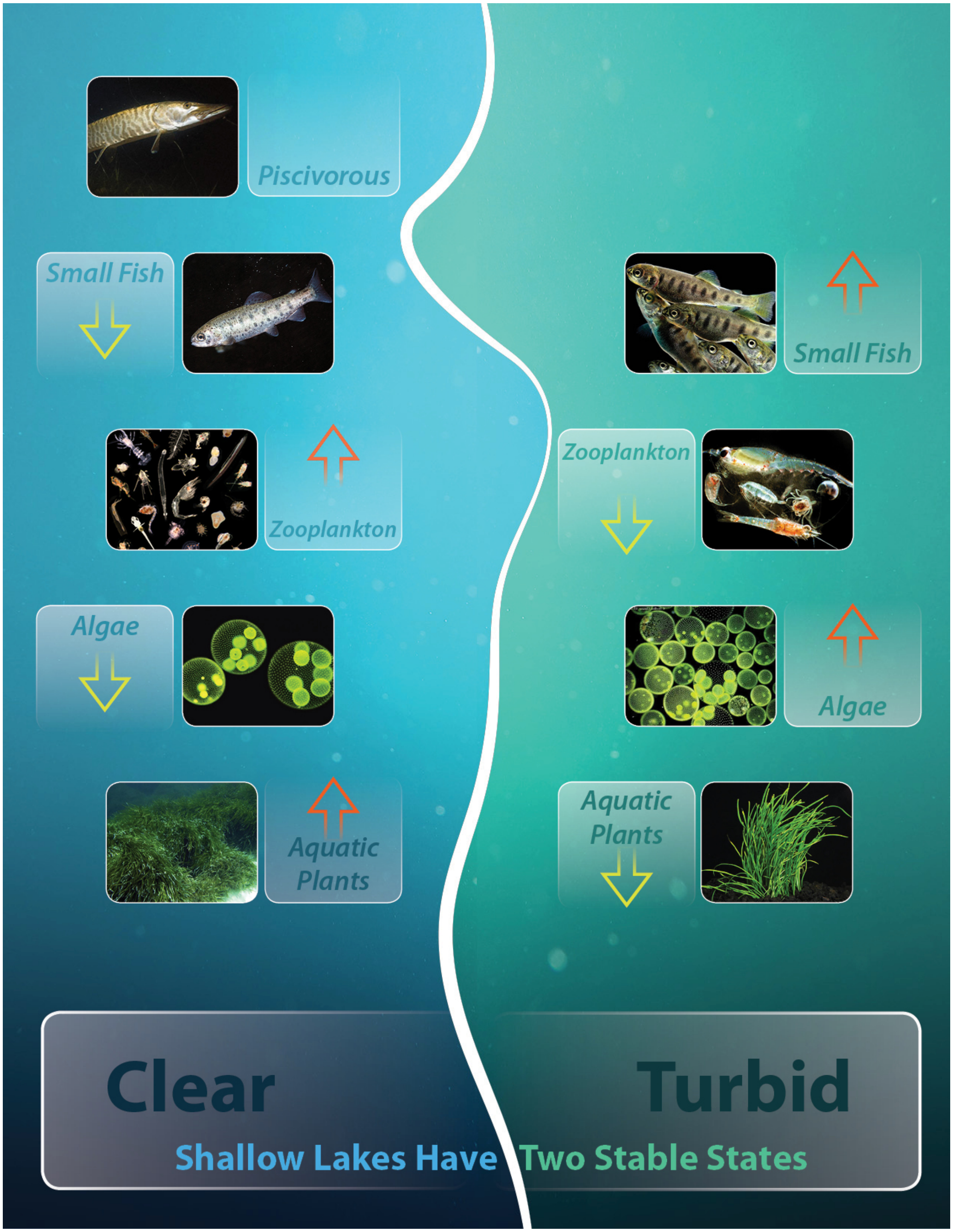


Figure 3. Cascading biological communities in shallow lakes under clear and turbid water states.

1.1. Aquatic Plants

In general, when aquatic plants are present in shallow lakes, the water is clear (Figure 3). Numerous studies have shown that native aquatic plants can sustain good light penetration and water quality, but the challenge is to establish aquatic plants if they are not present. The key to maintaining a clear water, aquatic plant dominated state is to control nutrients and other factors, especially fish disruptions as well as the introduction of invasive species that could limit plant establishment and growth.

While aquatic plants are vital to maintaining the ecologically-preferred clear water state, aquatic plants can prevent or restrict landowners from enjoying certain recreational activities such as boating and swimming.

Aquatic plants can contribute to the internal phosphorus load of lakes in two ways. First, the physical breakdown of plant biomass can potentially result in a large release of phosphorus into the water. Second, the decay of plant materials can also strip oxygen from the water column and cause a release of phosphorus from the sediments. As plant decay rates rise with an increase in the eutrophic nature (or fertility) of a lake, the bacteria involved in the decay of plant matter can also consume oxygen in the lake. Plant decay under ice cover is one of the mechanisms by which oxygen can become depleted in the winter and cause a fish kill (Figure 4).

1.2. Dissolved Oxygen Levels

Dissolved oxygen is the amount of oxygen dissolved in lake water. Individual fish species have different dissolved oxygen level requirements in water. Certain gamefish species, such as northern pike and yellow perch, are better suited for periodic low levels of dissolved oxygen than other gamefish species, such as walleye, bass, and bluegills. The major sources of dissolved oxygen in shallow lakes includes diffusion from the atmosphere, wind mixing (wave action), and photosynthesis from aquatic plants. The major uses of dissolved oxygen include respiration and decomposition. Respiration is essentially the act of breathing; when aquatic organisms breathe, they consume oxygen and release carbon dioxide. Decomposition is the breakdown of organic matter by invertebrates, bacteria, and fungi, which consumes oxygen. During the winter, shallow lakes can become anoxic (without oxygen) as oxygen consuming activities (respiration and decomposition) continue under the ice without any new sources of oxygen from the air or plant photosynthesis.

Installation of aeration equipment can create small plumes of oxygen for fish during periods of low oxygen. However, some shallow lakes are better managed as boom or bust fisheries in which gamefish are stocked following winterkills. These gamefish tend to grow fast due to the lack of competition with other fish for food following a winterkill. A boom or bust fishery maintains clear water by allowing zooplankton to forage on algae in the presence of no small fish immediately following a winterkill, or few small fish following gamefish stocking (Figure 3).

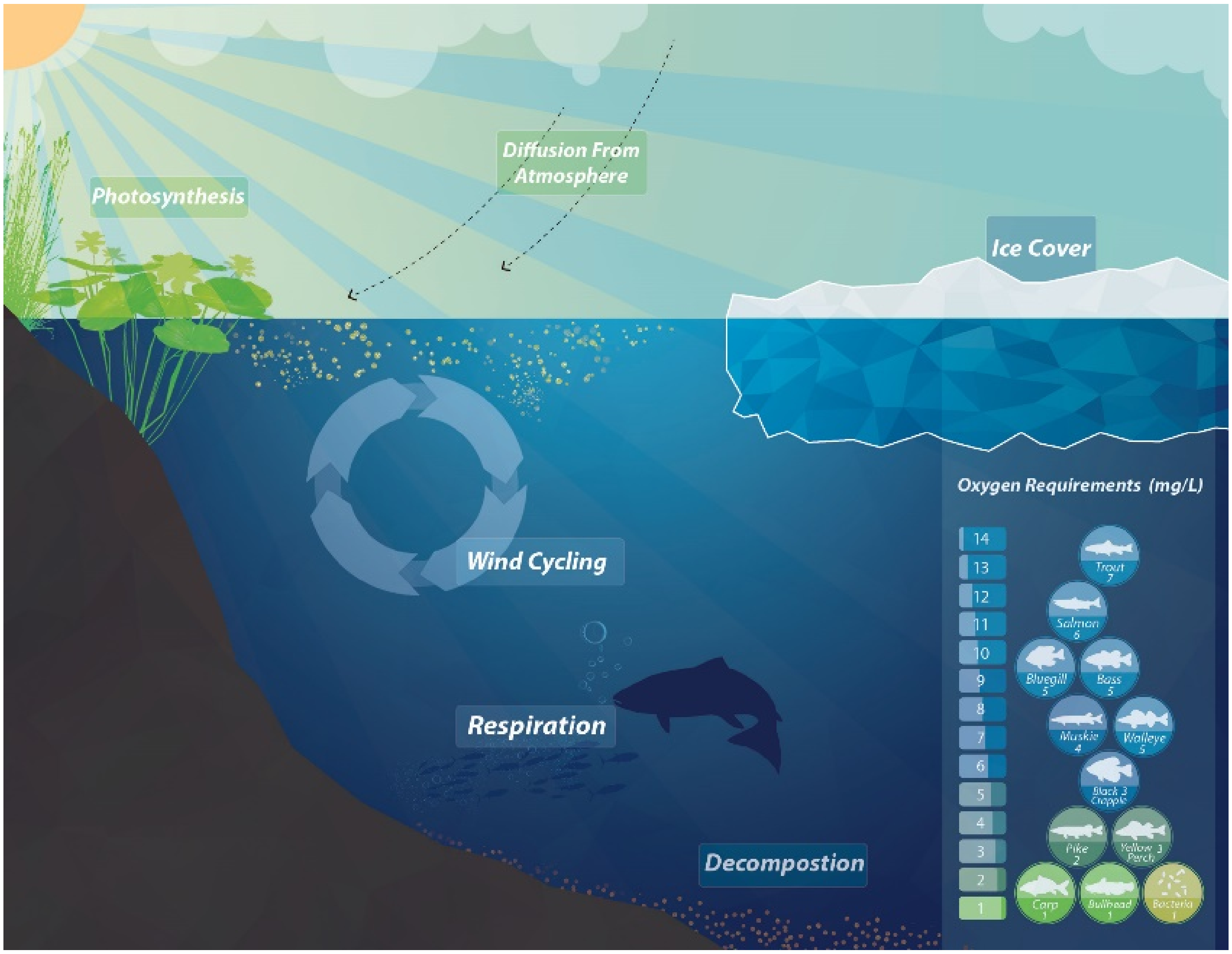


Figure 4. Dissolved oxygen dynamics in shallow lakes

2. BARTLETT LAKE AQUATIC PLANT AND FISH COMMUNITIES

Bartlett Lake (DNR Lake ID 36-0018-0) is a shallow lake located near Northome, MN in Koochiching County. Bartlett Lake has a surface area of 304 acres, a maximum depth of 16 feet and an average depth of 9 feet. The following section describes the aquatic plant and fish communities within the lake.

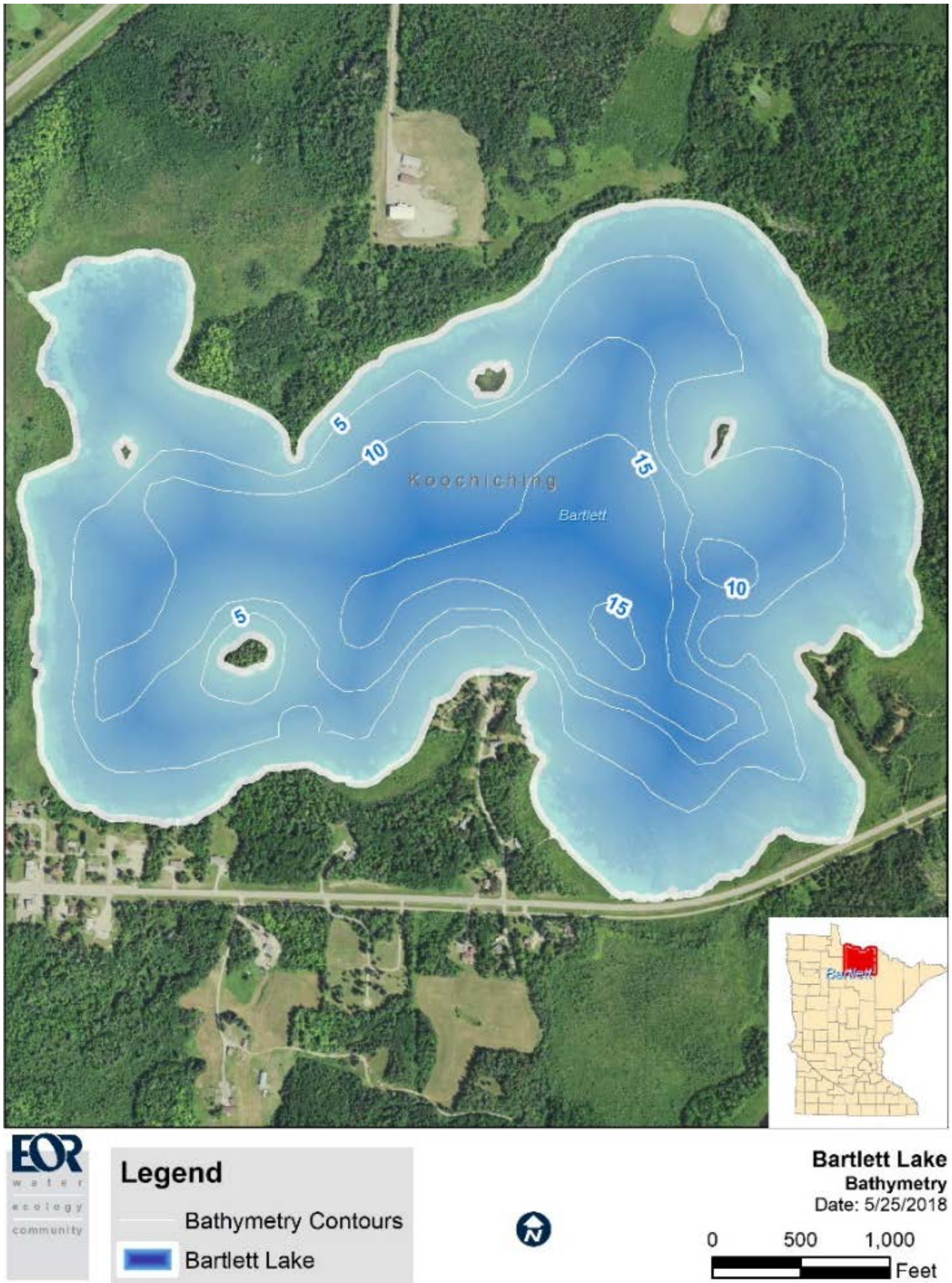


Figure 5. Bartlett Lake bathymetry (water depth) contours

2.1. Aquatic Plant Survey Results

The Minnesota Biological Survey (MBS) conducted an aquatic plant survey on August 21, 2014 on Bartlett Lake. Water clarity during the time of the survey was noted as poor with dark, iron-colored water. The predominant substrates observed were sand and gravel in the main lake with silt and fibrous detritus in bays. Overall, the shoreline was noted as being mostly intact, heavily wooded, with areas of marsh and meadow.

From the MBS 2014 aquatic plant survey data, EOR calculated a Floristic Quality Index (FQI) which was used to measure the diversity and health of the aquatic plant community. The FQI calculation is based on both the quantity of species observed (species richness) as well as the quality of each individual species. Every aquatic plant in the state of Minnesota has been assigned a coefficient of conservatism value (c-value) ranging from 0 to 10. The c-value of all aquatic plants sampled from a lake is used to determine the FQI for a given lake. Species with a c-value of 0 include non-native species such as curly-leaf pondweed (*Potamogeton crispus*) that are indicative of a highly disturbed environment. In comparison, the native species Oakes pondweed (*Potamogeton oakesainus*) has a c-value of 10 because this species is extremely rare and only found in undisturbed, pristine environments.

The results of the Bartlett Lake survey are summarized in Table 1. Included in the table is a list of aquatic plants sampled and their associated c-values. Several species with a c-value of 7 or higher were observed; species with a c-value of 7 or higher are typically correlated with healthy, undisturbed, aquatic plant communities. A healthy, native aquatic plant community represents an important resilience mechanism for deterring the establishment of introduced invasive species such as curly-leaf pondweed and Eurasian watermilfoil. Invasive species are more likely to become established in areas left open by the absence of a healthy, native aquatic plant community.

The average FQI score for Minnesota Lakes is 23.7±8 with a median of 25.2 (Radomski and Perleberg, 2012). The average FQI score for the lakes in the Northern Lakes and Forest (NLF) ecoregion is 28.5±6. The FQI score of 30.0 for Bartlett Lake is reflective of the high quality nature of the aquatic plant community which currently contains no invasive species. The Minnesota DNR recently conducted a review of plant surveys conducted on 3,254 lakes across the state. They concluded that the presence of water marigold (*Bidens beckii*) was a good indicator of a highly diverse aquatic plant community. The presence of water marigold in Bartlett Lake provides additional evidence to suggest that the aquatic plant community is diverse and healthy.

Table 1. Bartlett Lake August 2014 aquatic plant species and Floristic Quality Index c-values

Common Name	Scientific Name	C-Value
Blunt-tipped Sago Pondweed	*Stuckenia filiformis*	8
Bushy Pondweed, Common naiad	*Najas flexilis*	6
Canada waterweed	*Elodea canadensis*	4
Clasping-leaf pondweed	*Potamogeton richardsonii*	5
Crested arrowhead	*Sagittaria cristata*	8
Flatstem pondweed	*Potamogeton zosteriformis*	6
Floating-leaf arrowhead	*Sagittaria cuneata*	6
Floating-leaf pondweed	*Potamogeton natans*	5
Fries pondweed	*Potamogeton friesii*	8
Giant bur-reed	*Sparganium eurycarpum*	5
Hard-stem bulrush	*Schoenoplectus acutus var. acutus*	6
Narrow-leaved cat-tail	*Typha angustifolia*	0
Northern watermilfoil	*Myriophyllum exalbescens*	7
Sago pondweed	*Stuckenia pectinata*	3
Sessile-fruited arrowhead	*Sagittaria rigida*	7
Small Spikerush	*Eleocharis palustris*	5
Variable pondweed	*Potamogeton gramineus*	7
Very Small Pondweed	*Potamogeton pusillus*	7
Water horsetail	*Equisetum fluviatile*	7
Water marigold	*Bidens beckii*	8
Water stargrass	*Heteranthera dubia*	6
White water lily	*Nymphaea odorata*	6
Wild rice	*Zizania palustris*	8
Yellow pond lily	*Nuphar lutea ssp. pumila*	9
Summary Table FQI = C*√S C= Mean coefficient of conservatism value S= Number of species in sample	**Average C-Value**	6.125
	Number of species	24
	FQI	**30.0**

2.2. Fisheries Survey Results

The DNR has conducted several fisheries assessments of Bartlett Lake dating back to 1946. A comparison of the total biomass of species sampled within Bartlett Lake from 1986 to 2016 is provided in Table 1. As a general rule of thumb, the desired fish composition for shallow lakes is 30-40% piscivores or gamefish (Benndorf 1990).

Results from fisheries surveys conducted in 2007 and 2016 (post-winterkill events in 2004 and 2014) found healthy populations of quality-sized, desirable gamefish species including northern pike, yellow perch, and black crappie. The percentage of piscivore (northern pike) biomass to overall biomass was also highest in the years following winterkill events, indicating northern pike may have been providing top-down (predatory) control over other fish in these years.

While growth rates of desirable gamefish species are exceptional in Bartlett Lake, periodic winterkills have occasionally led to an unbalanced fishery dominated by tolerant species, specifically black bullhead. Black bullheads can tolerate high turbidity, low dissolved oxygen, and a range of temperature conditions that are lethal to most desirable gamefish species. Fisheries population surveys from 1986, 2000, and 2012 are examples of periods of time when the lake's fishery was unbalanced.

Results from the most recent (2016) fishery survey are especially encouraging with northern pike already averaging 4 pounds just two-years after a 2014 winterkill event. Several yellow perch were also captured that survived the 2014 winterkill event, including one individual that exceeded 12 inches. Similarly, northern pike stocked in 2004 and 2005 reached an average weight of 3.56 pounds by 2007, with individuals ranging from 18 to 28 inches in length following a 2004 winterkill event. Black crappie also showed good growth rates with individuals exceeding 8 inches in length by year 2. Black crappie were introduced in 2004. Since their introduction, observed growth rates have been some of the highest on record for the DNR Fisheries International Falls Management Area. Note that the 2007 and 2016 surveys were conducted following winterkill events in 2004 and 2014. Piscivore biomass was highest during these years which followed the change in the focus of fisheries management on Bartlett Lake in 2004.

Table 2. DNR Fisheries Surveys Results 1986-2016

Survey Year	Fish Species	Fish Count	Average Weight per Fish (lbs)	Total Biomass (lbs)	% Piscivorous
1986	Northern Pike	7	1.79	12.5	**20.9%**
	Yellow Perch	106	0.1	10.6	
	Brown Bullhead	99	0.37	36.6	
2000	Northern Pike	1	1.52	1.5	**0.8%**
	Yellow Perch	1,746	0.1	174.6	
	Brown Bullhead	39	0.15	5.9	
	Black bullhead	43	0.18	7.7	

Survey Year	Fish Species	Fish Count	Average Weight per Fish (lbs)	Total Biomass (lbs)	% Piscivorous
2007	Northern Pike	40	3.75	150	38.6%
	Yellow Perch	423	0.15	63.5	
	Black Crappie	343	0.16	54.9	
	Brown Bullhead	89	0.45	40.1	
	Black bullhead	1,143	0.07	80.0	
2012	Northern Pike	45	2.0	90	15.4%
	Yellow Perch	234	0.25	58.5	
	Black Crappie	117	0.65	76.1	
	Brown Bullhead	3	0.69	2.1	
	Black bullhead	1,022	0.35	357.7	
2016	Northern Pike	18	3.5	63	38.7%
	Yellow Perch	82	0.10	8.2	
	Black Crappie	409	0.15	61.4	
	Black bullhead	602	0.05	30.1	

Green shading = Piscivorous species (Feed on fish)

Yellow shading = Omnivorous species (Feed on plankton, insects, and crustaceans)

Brown shading = Rough fish (Omnivorous bottom feeders)

3. IN-LAKE MANAGEMENT RECOMMENDATIONS

To maintain a stable, clear water state in Bartlett Lake, the amount of algae must be controlled through either reduction in phosphorus loading (Figure 2) or management of the biological community (Figure 3). In-lake summer average phosphorus concentrations in the mid 1970's were 100-150 µg/L and have slowly been declining; recent in-lake summer average phosphorus concentrations are just exceeding state standards (30-40 ppb). The most recent DNR standard fish survey was completed on July 11, 2016. At this time, DNR noted that Bartlett Lake is a highly productive lake with a history of frequent winterkill events. But between winterkill events, Bartlett is capable of quickly rebounding to provide fish that are of interest to anglers.

Given the heavy aquatic vegetation, the success of the Northern Pike and Black Crappie fishery following the 2014 winterkill, and the current in-lake phosphorus concentrations near state standards, Bartlett Lake appears to currently be in a clear-water state. However, given the long history of historic phosphorus loading to Bartlett Lake from city sewer and a creamery, the stability of the clear-water state is likely weak. Therefore, at this time, EOR recommends management of the in-lake biological community of Bartlett Lake to support and maintain a clear-water state characterized by low algae, dense aquatic vegetation, and a healthy game fish population.

A summary of in-lake management alternatives, benefits, considerations, and applicability to Bartlett Lake are included in Table 1. In-lake management alternatives recommended for Bartlett Lake are described in more detail below, with a proposed implementation schedule and cost provided in Table 2.

3.1. Mechanical Harvesting of Aquatic Plants

Native aquatic plant biomass typically peaks in July during a period of time when average nutrient concentrations found in aquatic plants are also high. Small amounts of localized mechanical harvesting conducted during the month of July would have a high likelihood for removing a large pool of phosphorus from Bartlett Lake. Mechanical harvesting will not completely offset contributions from internal sources but may help to reduce the means by which the decay of senescing aquatic plants contributes to the internal phosphorus load of Bartlett Lake. Furthermore, mechanical harvesting will increase the usability of Bartlett Lake by providing boaters with easier access to the deeper, open water portions of the lake.

Typical costs for privately contracted mechanical harvesters in Minnesota range from $300 - $600 per acre. A point-intercept aquatic plant survey complete with estimates of aquatic plant biomass at each sampling location should be conducted prior to the survey to prioritize locations for harvesting. Rather than clear-cutting entire weed flats, mechanical harvesting can be used to cut paths within large weed flats which create "edge habitats" that support popular game fish species, including northern pike (Trebitz et. al., 1997). It is important to only cut small amounts of aquatic plants to maintain establishment of aquatic plants throughout the lake and promote clear water conditions.

Aquatic Plant Management Options and Permitting Requirements

Submerged aquatic plants are very important for lake water quality and fish communities. Therefore, DNR has set up conditions for the treatment or removal of aquatic plants. Any aquatic plant harvesting or removal should be done with great care and to the minimum amount practicable.

<u>Treatment options that do not require a Permit:</u>

The DNR has established thresholds for the physical removal of aquatic vegetation which allow lakeshore owners to create or maintain a swimming or boat docking area without a DNR permit under certain conditions. A DNR permit is not needed for the following physical removal activities:

- First, the clearing or removal of **submerged** vegetation up to 2,500 square feet
    - The 2,500 square foot area may also include a boat channel up to 15 feet wide, and as long as necessary to reach open water (the boat channel is in addition to the 2,500 square feet allowed). The cutting or pulling may be done by hand or with hand-operated or powered equipment that does not significantly alter the course, current, or cross-section of the lake bottom.
- Second, the cleared areas must not extend more than 50 feet along the property owner's shoreline or one-half the length of the property owner's shoreline, whichever is less.

<u>Treatment options that require a Permit</u>

- Destruction of any **emergent** vegetation (cattails, bulrushes, etc.)
- Physical removal involving an area exceeding 2,500 square feet
- Applying herbicides or algaecides
- Moving or removing a bog of any size
- Transplanting aquatic plants
- Use of automated aquatic plant control devices.

3.2. DNR Fisheries Management

A Ramco Bubbler aeration system with two, 5-horsepower motors installed in 1985 was not able to maintain sufficient dissolved oxygen concentrations in Bartlett Lake and a substantial winterkill event of stocked walleye was noted while the aerator was in operation (DNR 2017, pers. comm.). The DNR changed the focus of fisheries management on Bartlett Lake in 2004 following a comprehensive planning effort that involved local stakeholders from the City of Northome and the Koochiching County Environmental Services Department. The fisheries management plan now focuses on stocking northern pike and black crappie which are more tolerant of low dissolved oxygen concentrations.

Shallow, productive lakes like Bartlett Lake that contain piscivorous fish species that experience rapid growth rates following winterkill events are known as "boom or bust" fisheries. Stocked gamefish are able to grow rapidly following a winterkill since there are no other piscivores to compete with for forage. At times, these boom and bust fisheries can provide outstanding angling opportunities if environmental conditions are right, such as a period of 2-3 mild winters with reduced snow and ice cover. Results from the post-winterkill fishery surveys conducted in 2007 and 2016 suggest that the current fisheries management approach (boom or bust fishery) is working with outstanding growth rates observed for northern pike, yellow perch, and black crappie. The success of the boom or bust fishery in promoting a clear water state in Bartlett Lake is also evident in the recent low in-lake phosphorus concentrations and clear water.

The DNR has established the following long-range goals for Bartlett Lake:

- Maintain a black crappie and northern pike fishery between winterkill events to provide angling opportunities for the public.
- Black crappie trap net catch rates should be greater than 3.5 fish per set.
- Northern pike gill net catch rates should be between 3 and 8.3 fish per set with mean length at age 4 greater than the International Falls Management Area mean of 23.3 inches.
- Consider stocking largemouth bass to provide additional top-down control over black bullheads.

To meet these long-term goals, the DNR has established an operational plan which begins with checking dissolved oxygen concentrations annually at approximately March 1st to determine if winterkill is likely. If winterkill is suspected, the DNR will set 6 trap nets after ice-out to determine the extent of winterkill. If the trap net catch per unit effort (CPUE) is below 2.0 black crappie per net, 200 mature, black crappie will be stocked for two consecutive years. If trap net CPUE for northern pike is below 3.0 fish per gill-net, the DNR will stock 300 adult northern pike every other year. The northern pike stocking quota is based on a population goal of 0.8 northern pike >24 inches per acre as recommended by DNR Fisheries Research Biologist Rod Pierce. Associated costs for stocking are covered by the International Falls Management Area budget and/or statewide resources because stocking is called out in the approved lake management plan for Bartlett Lake.

We recommend support of DNR's fisheries management approach.

3.3. Landowner Education

In addition, we recommend informing landowners about aquatic plant regulations and the importance of aquatic plants to lake water quality. Often landowners perceive heavy 'weed' growth as indicators of poor water quality, but maintaining the existing submerged aquatic vegetation is critical for supporting a clear-water state in Bartlett Lake.

3.4. Monitoring

Because shallow lake management can sometimes be unpredictable, we recommend additional water quality monitoring and evaluation of the in-lake biological community to determine if and when further management activities are needed. Very little phosphorus and chlorophyll-a (algae) data has been collected in Bartlett Lake (1976-1978 and 2014-2015). To better understand the response of Bartlett Lake to shifts in the biological community (such as before and after a winterkill) we recommend collecting twice monthly water quality samples for phosphorus, chlorophyll-a and Secchi depth transparency in May through September and a point-intercept aquatic vegetation survey every other year. DNR will be conducting fisheries surveys once every five years.

Table 3. In-Lake Management Alternatives: Benefits, Description, Considerations and Applicability to Bartlett Lake

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Whole-lake Drawdown • Reduce sediment phosphorus loading • Increase water clarity • Re-establish submerged aquatic vegetation • Fish kill	A whole-lake drawdown is the process of passively or actively removing all water in a lake and exposing the entire lake bottom to the air to: a) oxidize and consolidate sediment, b) freeze curlyleaf pondweed turions if present, c) kill all fish, and d) promote re-germination of native plant species. This activity simultaneously achieves all shallow lake key functions.	Lake aesthetics may be moderately impacted, and consideration must be given to downstream discharge of the high phosphorus lake water. An outlet structure system and a downstream resource capable of receiving the drawdown water are needed. Best in fall/winter when runoff low.	**No.** No outlet structure nor downstream resource capable of receiving the drawdown water.
Sediment Alum Treatment • Reduce sediment phosphorus loading • Reduce algae blooms • Increase water clarity	The application of aluminum sulfate as a floc layer at the lake sediment/water interface that can bind with phosphorus released from the sediments for an extended period of time. The aluminum sulfate used in alum treatments strongly binds with phosphorus through a chemical reaction under most lake conditions, prohibiting phosphorus release from the sediments into the lake water. Alum will also strip phosphorus from the water column as it is applied, resulting in immediate improvements in water clarity and algae. When applied at an appropriate dose, alum will prevent internal recycling of phosphorus over 5-10 years.	Usually applied with a buffer, to maintain appropriate lake pH levels. Requires lake access for application pontoons or barges. There are a finite number of alum binding sites in each alum treatment that are used over time as phosphorus is slowly released by the lake sediments. Therefore, additional alum treatments are needed to replenish the amount of available alum binding sites for sediment phosphorus. Best in late fall or early spring, when aquatic plant growth is minimal and water temperatures are above 40 degrees F. Treatment longevity averages 5.7 years in shallow lakes and 21 years in deeper, stratified lakes (Hanson et al. 2017).	**No.** Internal load 75% of total phosphorus load to lake, but heavy aquatic vegetation would interfere with treatment. High cost and short longevity in large, shallow lakes.

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Sediment Iron Filings • Reduce sediment phosphorus loading	Recent research at the University of Minnesota on lake sediment cores suggests that the application of zero-valent iron metal filings to lake sediments may be a potential phosphorus reduction tool.	The weight of the amount of iron filings needed to treat a large lake may currently be impractical. Few large scale treatments have been completed to test the effectiveness of iron filings to reduce internal phosphorus load at the lake scale.	**No.** Currently cost prohibitive and relatively untested. May be a consideration as a future follow-up treatment.
Sediment Dredging • Reduce sediment phosphorus loading • Increase lake depths	Dredging permanently removes phosphorus laden sediments and increases lake depths.	Disposal of dredge sediment is a difficult/expensive effort due to the water content and weight of the material. Large, nearby drying areas are needed to reduce the water content of the sediment prior to disposal. Dredging will also remove the seedbank within the lake, destroy in-lake habitat and temporarily increase lake turbidity.	**No.** Cost prohibitive and destructive. Accumulated sediment evenly distributed throughout lake.
Algaecides • Reduce algae blooms • Increase water clarity	Temporary chemical treatment of algae to reduce an algae bloom.	Requires regular monitoring throughout the season, and multiple treatments on an as-needed basis. Reactive approach and does not solve root of water quality problem, just a temporary treatment of the symptom.	**No.** Temporary aesthetic treatment.
Hypolimnetic Aeration • Reduce sediment phosphorus loading • Reduce algae blooms • Increase water clarity	Add air to bottom waters (hypolimnion). Goal is to ensure that bottom waters are oxygenated so that phosphorus is not released from sediment. Appropriate for lakes with high sediment internal load that would benefit from oxic bottom waters.	Requires electricity and ongoing maintenance. For lakes with undesired winter fish kill, can also be used in winter to prevent fish kill. Most applicable to deep lake bottom waters, or to very small treatment ponds.	**No.** Lake too large and shallow. Lake does not strongly stratify.

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Mechanical Harvesting • Manage aquatic invasive plants & heavy plant growth	Cutting and removal of aquatic vegetation. Goal is to remove vegetation from the water to eliminate it as a source of nutrients as the vegetation degrades, and encourage growth of native plants.	Ongoing harvesting needed, minimize harvesting only to areas needed to provide recreational access to the lake.	**Yes.** Can reduce dense mats, enhance recreational value, and remove source of nutrients to the lake.
Herbicides • Manage aquatic invasive plants	Application of chemical herbicides to the littoral area of the lake. Goal is to kill aquatic vegetation to eliminate it as a source of nutrients. Endothall is often used for curly-leaf pondweed control.	Properly applied herbicides generally have little effect on overall native aquatic plants, though can change species abundance. Multiple years of treatment are needed to manage plant growth. Will not eradicate plants. Best in late spring when CLP growing.	**No.** No aquatic invasive plant species present.
Fish Kill • Manage biological community • Reduce algae blooms • Increase water clarity	Kill fish population using pesticide. Goal is to eliminate an unbalanced fish population in order to re-establish a healthy fish population. Allows lake to be "restarted" with fully defined new fish population. Treatment has been able to shift shallow systems to clear water state for a period of time (many years).	Kills all fish, but not usually black bullheads or carp. May also kill zooplankton. May limit use of lake as habitat for wildlife because of lack of available food (fish). Need to rotenone entire watershed to be most effective, or conduct regular treatments. Best in winter when oxygen concentrations are lowest.	**No.** Can support Northern Pike. Manage lake for game fish control of algae.
Fish Stocking • Manage biological community • Reduce algae blooms • Increase water clarity	Alteration of fish population structure. Goal is to alter fish population structure so that fewer planktivorous fish are present, leaving the zooplankton present to reduce the algae population.	May not be effective if high internal load from sediment still present. May take a long time to see full effect of biomanipulation efforts. Best in early spring to allow juvenile fish to grow during warmer summer months.	**Yes.** Can support game fish. Manage lake for boom or bust fishery.

In-lake Management Alternative Benefits	Description	Considerations	Applicable to Bartlett Lake?
Winter Aeration • Prevent winterkill	Maintain a small plume of high oxygen water in the lake. Goal is to eliminate winter fish kills. Increases oxygen to maintain game fish species with minimal energy consumption. Takes away competitive advantage of bullheads and carp under low oxygen conditions.	Requires electricity and ongoing maintenance. Must obtain a permit to install and fence off aerated lake area. Best to begin aeration soon after ice over.	**No.** Past winter aeration systems installed by DNR unable to prevent winterkills. Utilize occurrence of winterkills to promote a boom or bust fishery.

Table 4. Recommended Implementation Schedule and Budget

In-lake Management Activity	Partners	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Mechanical harvesting	DNR		$5,000		$5,000		$5,000		$5,000		$5,000
Aquatic vegetation point-intercept survey			$5,000		X		$5,000		$5,000		$5,000
DNR fisheries standard survey, aquatic vegetation sampling, and lake management plan update	DNR Fisheries - International Fall				X						
Landowner education	Koochiching SWCD	X	X				X	X			
Lake water quality monitoring	Red Lake DNR	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
TOTAL		**$3,000**	**$13,000**	**$3,000**	**$8,000**	**$3,000**	**$13,000**	**$3,000**	**$13,000**	**$3,000**	**$13,000**

APPENDIX A. REFERENCES CITED

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