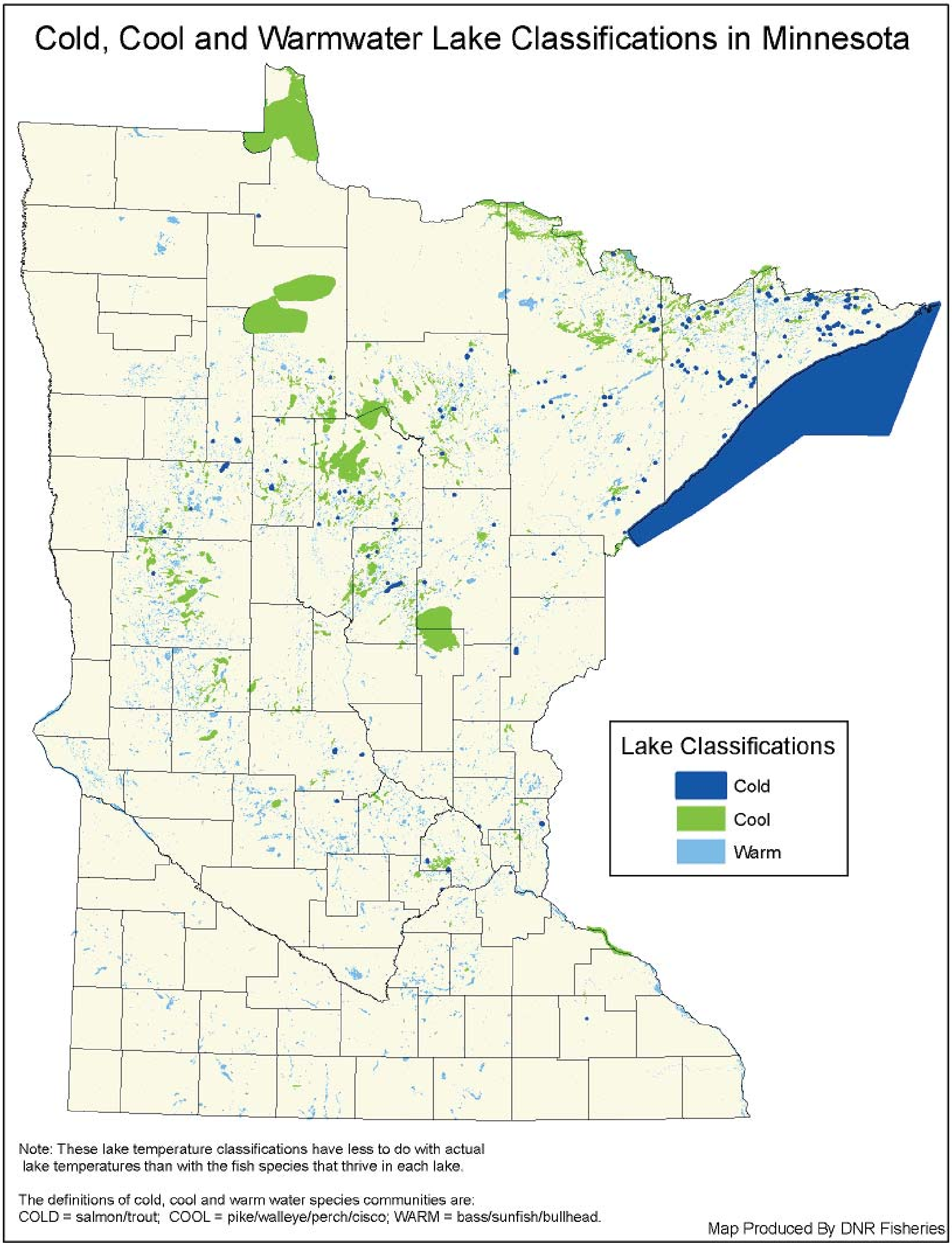

Figure 1: Minnesota is blessed with diverse lake and stream fish communities. This map shows three major classifications of lake fish communities, with cold water species mainly in the north, coolwater species in the north and central areas, and warmwater species ocurring throughout the State but dominating in the south. These communities and quality fishing depend on healthy environmental conditions in the water and on the surrounding lands. Credit: Minnesota DNR

"The sparkling trout streams, like silver ribands, thread their way across the verdure of the prairies… Only a few years ago…in all and every stream were to be found food fishes; not here and there one, but by myriads. The little brooks where leaped the speckled trout…the approach and contact of civilization has changed all this… let us call a halt; it is time. Let us make every effort, every man of us, to save this wonderful heritage from destruction. Let us spare something for coming generations."

—Letter to Governor Merriam from Robert Ormsby Sweeny, Sr., President, MN Game and Fish Commission, in 2nd annual report to the Governor, 1892

Figure 2: Good trolling – 362 pounds of trout from White Fish Narrows, Lake of the Woods circa 1915. Credit: Minnesota Historical Society.

History: Demise to Hope

The history of Minnesota's fish communities since European settlement is one of major declines. Early explorers described clear streams writhing with abundant brook trout and other fishes, flowing through prairie country alternating with heavily timbered areas. Brook trout were so rapidly harvested that as early as the 1870s one writer referred nostalgically to their "former" abundance. At the time of settlement, Lake Superior and its rivers had over 70 native fish species, including lake trout, brook trout, walleye, lake sturgeon, yellow perch, and northern pike. An 1865 account described an "abundance of brook trout, averaging over two pounds, [along] the entire rocky shore of the lake, along both coasts…". After settlement, many fish and other aquatic wildlife declined precipitously. In Lake Superior, the 'coaster' brook trout that were so abundant in 1865 disappeared from the North Shore, and arctic grayling disappeared from the watershed. Minnesota waters of the Mississippi River once sheltered a symbiotic relationship between huge schools of skipjack herring and millions of ebonyshell mussels, whose shells are an essential ingredient for the modern pearl industry. Construction of locks and dams blocked the herring runs from the Upper Mississippi and ebonyshell mussels, which depend on this fish to host its young, became so rare that they will likely disappear from Minnesota within 10 years.

In 2006, the DNR designated 32 percent of fish and 33 percent of mollusk species in Minnesota as being in greatest need of conservation. Early losses were due to unregulated fishing (see Figure 2) and massive changes to aquatic habitats. Later declines resulted from ineffective fishing regulations, water pollution, and massive land and shoreline development. Early cases of nuisance aquatic invasive species, such as sea lamprey and common carp, resulted from introductions or expansion of shipping, particularly into Lake Superior. A few hard lessons have been heeded. Minnesota today has broadly effective fishing regulations and cleaned up some sources of water pollution. Yet, it is hard to imagine society choosing to make the many changes required to restore Minnesota's fish communities to their once amazing abundance and quality. Fortunately, existing fish communities have many features worthy of conservation.

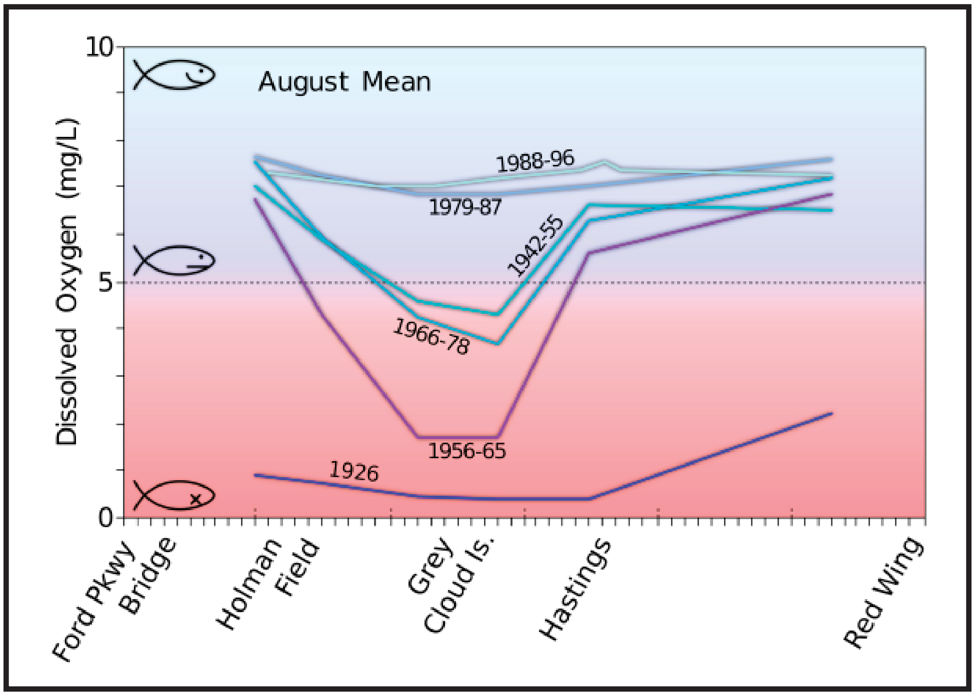

Figure 3: Long-term trends in dissolved oxygen levels in the Upper Mississippi downstream from the Metro waste treatment plant in Saint Paul.
Credit: Terry Brown, University of Minnesota, based on US EPA graphic.

Experience since the mid-20th century shows that heavily impaired fish communities can be rehabilitated by implementing appropriate policies and embracing a decades-long commitment to achieve recovery goals. In the Upper Mississippi River, installation of sewage treatment plants restored a river that was nearly dead in the 1920s to healthy levels of dissolved oxygen for native fish species (see Figure 3). Another success involves lake trout along the North Shore of Lake Superior, whose numbers had plummeted due to heavy fishing, severe habitat destruction, and invasive sea lamprey impacts. Forty years of multiple actions to mitigate these harms led to re-establishment of naturally reproducing populations. In 2003, fisheries managers concluded Lake Superior's fish community is "reverting to a more natural state resembling historical conditions and requiring less management intervention and control."

Drivers of Change

Fish provide many benefits to people. Minnesota is nationally recognized for its successful fisheries management programs and quality fishing opportunities. However, the future is threatened by cumulative impacts to the resource. Fish live in the lowest part of the landscape – the streams, rivers and lakes of Minnesota. They are sensitive to a host of changes including climate change, land use, water resources, aquatic habitats and invasive species. This puts them at the receiving end of more human causes of environmental change than other natural resources. All these drivers of change are converging to degrade the habitats and productivity of fish communities statewide. The Fish Research Team used its analysis of past to present conditions of fish communities to suggest priority public investments to address these cumulative impacts (see Appendix II).

Aquatic Invasive Species

Minnesota has sixteen aquatic invasive species of serious concern (see Table 1, facing page) and many potential invaders. A deadly fish virus, viral hemorrhagic septicemia (VHS), kills many fish species and will likely soon invade Minnesota. Aquatic invasive species can directly affect native fish communities through predation, competition, modification of food webs and habitat. Once invasive species become well established, they are nearly impossible to eliminate, and often require a long-term control program. Restrictions to prevent introduction and spread of invasives can impede fishing and fisheries management, and many control measures can harm native fish communities and habitats.

Invasive species threaten a number of native fish and aquatic animals in Minnesota. The sea lamprey contributed to the decline of lake trout throughout the Great Lakes. Lake trout populations are now recovering in Minnesota waters of Lake Superior, but this has required continuous sea lamprey control since the 1960s, at a current annual cost of $13 million across the Great Lakes plus millions more in annual costs to rehabilitate lake trout populations. Zebra mussels threaten native mussels (some already threatened and endangered) in the St. Croix and Mississippi Rivers and will threaten other mussels if introduced elsewhere. The New Zealand mudsnail which is a recent introduction to Duluth Harbor can out-compete native animals and suppress the growth and condition of trout.

Invasive species can also disrupt fishing activities. The recent invasion of the spiny waterflea (see Figure 4) in the Rainy River resulted in restrictions on bait, water and hatchery fish transport. Control measures for invasive species can have negative effects on fish habitat and fisheries. New infestations of zebra mussels often go uncontrolled because available methods would kill most other fish and invertebrates in the area. The most effective control for carp and other invasive fish, are chemicals that will also kill most other fish and are expensive to apply over broad areas. Even somewhat selective aquatic plant chemical controls can have negative effects on fish communities and habitat. For example, whole lake treatments to control Eurasian watermilfoil can also kill native plants and the resulting lower water clarity persists for several years after treatment.

Figure 4: Spiny water flea on a fishing line. Credit: ©Jeff Gunderson, Minnesota Sea Grant Program.

Through laws, regulations and boater education, the spread of invasive species to inland lakes is slower in Minnesota compared to neighboring states, yet prevention is not perfect and new infestations are found each year. For example, curlyleaf pondweed has invaded over 700 lakes and Eurasian watermilfoil is now in over 190 water bodies (see Figure 5, next page). Although Eurasian watermilfoil infestations may have saturated Metro Area lakes, infestations are increasing in Greater Minnesota and more than 1,900 lakes have a higher potential to become infested. Meanwhile, several new invasive species are poised to enter the state. Asian carp are moving up the Mississippi River. There is grave concern about the expected arrival of an incurable viral disease, VHS to Minnesota. It has already invaded Lake Winnebago in Wisconsin. Many fish species are vulnerable including such sport fish as walleye, muskies, northern pike, trout and bass.

Table 1: Established aquatic invasive species of serious concern in Minnesota.

Fish	Aquatic Invertebrates	Aquatic Plants
Common carp	Chinese mystery snail	Curlyleaf pondweed
Ruffe	Japanese mystery snail	Eurasian watermilfoil
Sea lamprey	New Zealand mudsnail	Purple loosestrife
Round goby	Rusty crayfish	Flowering rush
Tubenose goby	Spiny waterflea	
White perch	Zebra mussel	

Better risk assessment approaches are needed to identify likely invaders and the pathways of entry so that they can be managed to prevent new introductions. Assessment and implementation of the most effective approaches to prevent the spread of invasives within the state is needed. Effective and environmentally-sound control measures for all current and potential invasive species must be developed. All of

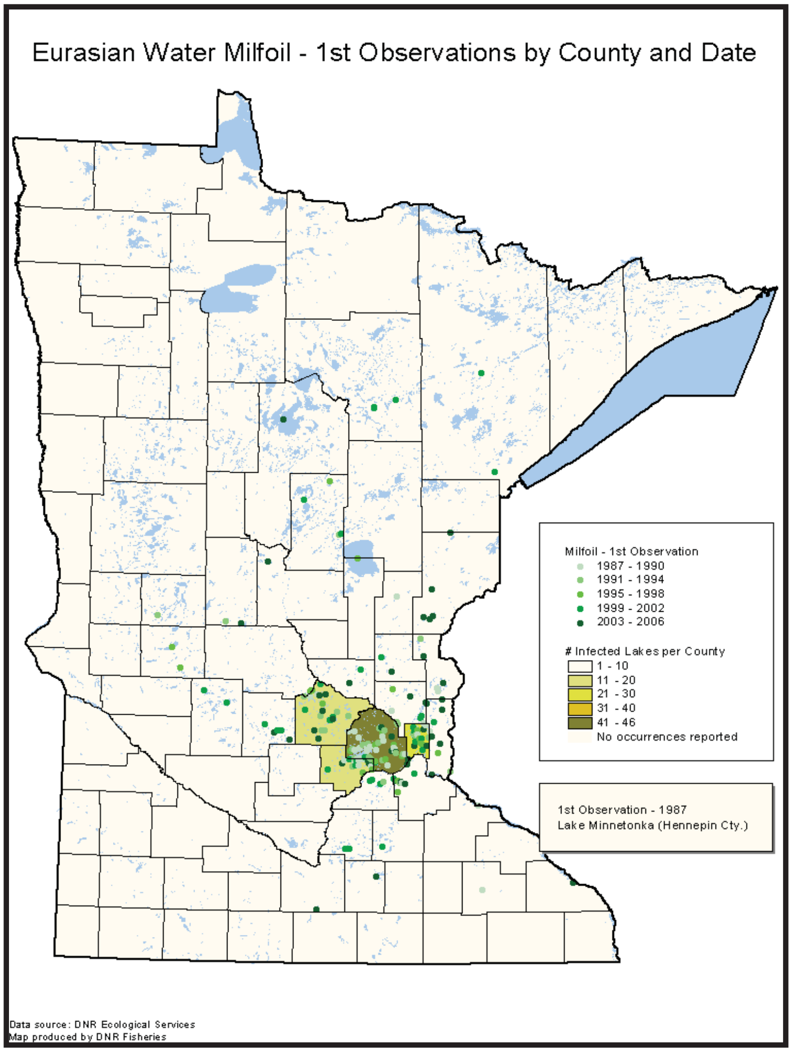

Figure 5: Eurasian watermilfoil – First Observations by County and Date. Credit: Minnesota DNR.

these require a good understanding of the basic life history, physiology and ecology of the invasive species.

Nutrient Loading

The loading of nutrients such as nitrogen and phosphorus above the natural levels in lakes, rivers, and streams can indirectly harm the fish community. Profligate nutrient loading in the past has severely harmed fish populations in many rivers and streams, notably the Mississippi and Minnesota Rivers. Contemporary pollution control regulations are limiting the input of nutrients and leading to some improvements in water quality and aquatic fish communities. Yet, a recent study found that one-third of Metro and central Minnesota lakes have significantly higher phosphorous levels than they did in 1800. Water clarity is a useful indicator of nutrient loading to lakes. Satellite imagery of water clarity of 481 Minnesota lakes showed that between 1973 and 1998, 6.8% improved, but 6.4% became less clear and the remainder did not change (see Figure 6, facing page).

Nutrients added to water are akin to adding fertilizer to an agricultural field in that they stimulate plant growth. This leads to increased production of all forms of aquatic plant life, from algae to rooted plants. Major sources of nutrients in water bodies in Minnesota are municipal sewage treatment plants, agricultural runoff, and industry discharges like food processing, pulp and paper. Increased algal production may provide additional food for organisms that fish depend on for their food but may also change the food web. Increased production of algae and rooted plants may also change the structure of the habitat for fish.

Lakes and their fish communities may be classified into three general types based on their nutrient load: oligotrophic (infertile and high water clarity), mesotrophic (moderately fertile and medium water clarity), and eutrophic (highly fertile and low water clarity). In Minnesota, lake trout, smallmouth bass, and walleye are characteristic of oligotrophic lakes; walleye, bluegills, northern pike, and largemouth bass are found in mesotrophic lakes; and in eutrophic lakes, walleye tend to disappear and carp become common, sometimes dominating the fish community. Nutrient enrichment will shift fish communities from oligotrophic to eutrophic types. Recent studies have shown that some fish species have disappeared in response to increases in nutrients in Minnesota lakes.

A similar phenomenon occurs in rivers and streams, but there it tends to result in a spatial change in the fish community, rather than a change over time. In the vicinity of the nutrient input, plant abundance increases and this changes the mix of fish species. If

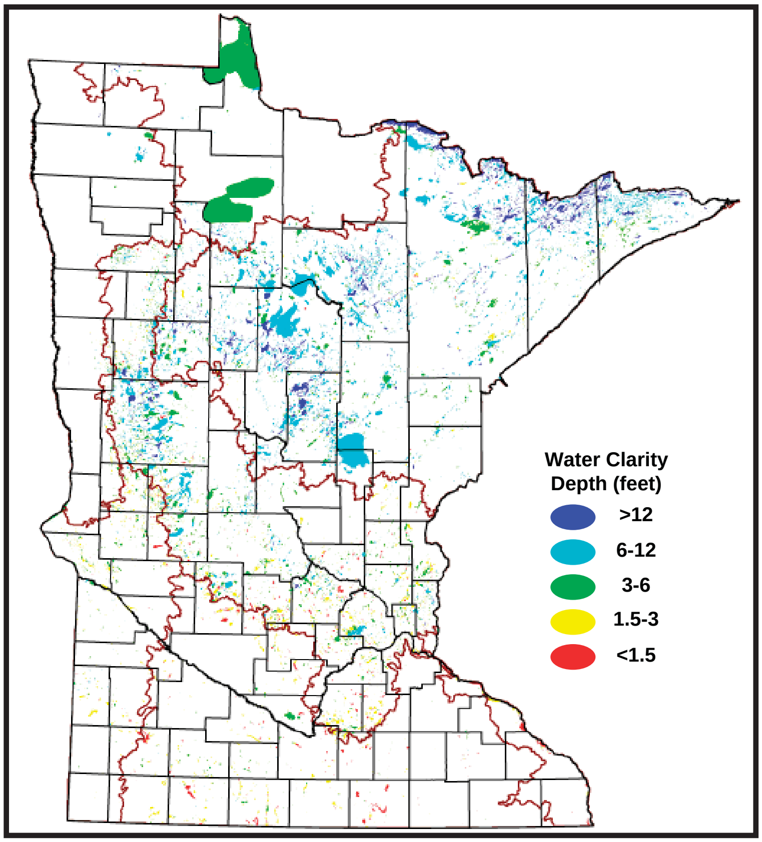

Figure 6: Year 2000 census of lake water clarity, a useful indicator of nutrient loading to lakes. Credit: University of Minnesota and LCCMR.

no additional nutrients enter the stream, the nutrient load is gradually assimilated as the water flows downstream until the stream returns to its original condition. If nutrients are added continually, the river or stream may never return to its original condition. Some stream fish communities are recovering in response to reductions in nutrient loads but others are still suffering. For example, between 1991 and 2001 the fish communities in the Minnesota River watershed improved in 14 streams, remained the same in seven, but declined in 10 streams.

Solids Loading

Sediment—primarily clay, silt, and fine sand— has been labeled the most important pollutant in the streams and rivers of the United States, both in terms of quantity and economic impact. Whereas some sediment is normal in the bottoms of streams, excess sediment resulting from human activity has caused degradation in streams and rivers across the nation. In the Midwest, the primary causes are row crop agriculture, livestock grazing and timber harvesting.

Laboratory experiments on suspended sediment at high concentrations have shown that sediment damage to the gills of fish and other aquatic organisms can cause death by suffocation. But the major impact of sedimentation on populations of fish and invertebrates has been by deposited sediment. It covers fish eggs during incubation and hiding places of aquatic insects and other invertebrates which are the primary food of fish. Deposited sediment also may fill the small spaces in bottom gravels that harbor the larvae and early life stages of many species of fish, particularly during winter periods when ice conditions may prevent normal feeding behavior.

In the mid-1960s, a massive sedimentation event into a small Minnesota trout stream from a poorly-located and designed housing development caused the loss of an entire year-class of trout. It decimated the population through loss of their major food source and contributed to a permanent change for fish species in the streams. Less egregious but still harmful sedimentation continues today. In 2004 and 2005 heavy runoff flushed sediment into some SE Minnesota streams and depressed trout reproduction.

Minnesota needs basic data on normal sediment loading in our prime recreational rivers. This data collection could be added to the many ongoing stream monitoring programs. Restoration of perennial vegetation on shorelands surrounding streams and lakes is also essential.

Dissolved Oxygen

Dissolved oxygen is critical for fish. Without sufficient oxygen, all aspects of a fish's life history are affected: survival, growth, reproduction, and behavior. Although low dissolved oxygen sometimes occurs naturally, human activities often cause or exacerbate the effects of low oxygen on fish.

Nutrient additions often decrease the oxygen content of the water bodies due to decomposition of the nutrient material itself and increased respiration or decomposition of the more abundant plant life stimulated by the nutrients. As available oxygen declines, fish species intolerant of low oxygen levels disappear and are replaced by more tolerant species. The gradient of oxygen tolerance by Minnesota fish communities is similar to their tolerance of nutrient loading, as discussed above. Past changes to fish communities in Minnesota's large rivers receiving municipal and industrial wastes were due in large part to reduction in oxygen concentrations, particularly during the summer. Current pollution control regulations have reduced this cause of low oxygen.

A looming threat to Minnesota fish communities involves the relationship between high temperature and low oxygen. As temperatures rise, oxygen loss from water bodies increases, due to increased rates of decomposition and respiration. As temperatures rise, fish require more oxygen, due to decreased solubility of oxygen in warmer water, and this causes them even greater stress. Ongoing DNR studies show that as lakes become warmer due to climate change, habitat with suitable temperatures and sufficiently high oxygen concentrations is declining for coldwater fish species. Lake herring, an important food for large walleye, northern pike and lake trout, have declined in the last 20 years in some large Minnesota lakes and may disappear as these lakes get warmer (see Figure 7).

Contaminant Loading

Contaminants have been present in Minnesota waters since the establishment of towns and industry. Primary sources are municipal sewage, agriculture, and industry. Some of the most common and insidious toxicants that affect fish and other aquatic organisms are decomposition products of organic wastes (e.g., ammonia), heavy metals (e.g., mercury, zinc, cadmium), pesticides (e.g., insecticides, herbicides), endocrine disrupting compounds (e.g., estrogens, surfactants, insecticides), and pharmaceuticals (e.g., antibiotics, analgesics). Additional sources of toxicants are from atmospheric transport, such as mercury, PCBs, and acidifying materials (e.g., sulfur dioxide).

Sub-lethal effects of contaminants to fish communities are the dominant concern today. Although many toxicants found in Minnesota waters can be lethal to aquatic organisms at high concentrations, fish kills rarely occur except from accidental releases. Sub-lethal effects of toxicants cause subtle physiological, biochemical, and genetic changes, which may ultimately depress the abundance of some species.

Fish may accumulate and concentrate mercury, PCBs, pesticides and other toxicants within their bodies making them dangerous to wildlife and humans consuming them. Fish consumption advisories for many Minnesota lakes indicate the widespread nature of this problem.

Over the past 50 years, a tremendous amount of research has documented the effects of toxicants on fish and other aquatic organisms. Consequently, the U.S. Environmental Protection Agency developed

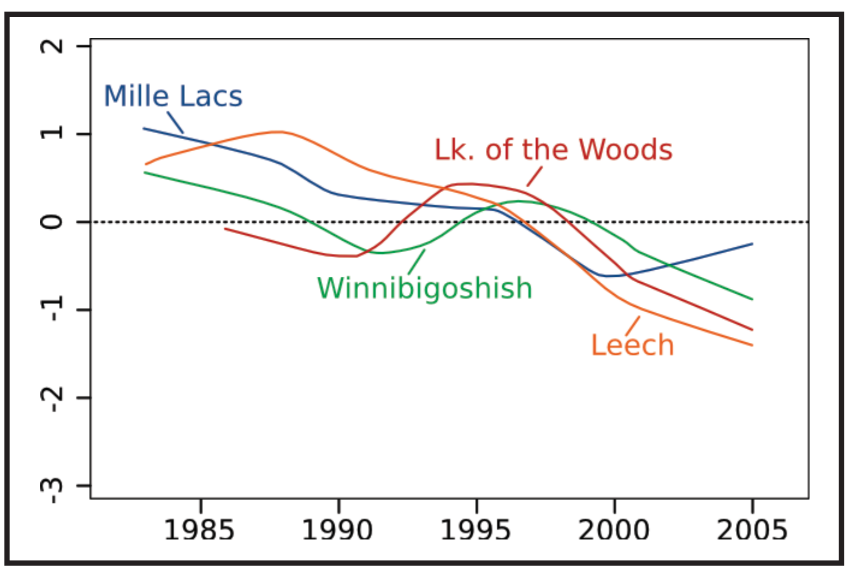

Figure 7 : Declines in abundance of lake herring (tullibee/cisco), an important food for large walleye, in Minnesota's large lakes in the past 20 years.
Credit: Don Pereira, Minnesota DNR

water quality standards for keeping toxicants below concentrations that harm aquatic organisms. Despite these advances, several problems persist. Enforcement of the standards is mixed. For example, the Minnesota Pollution Control Agency has only assessed ambient water quality in 10% of the river miles and 14% of the lakes that the Federal Clean Water Act mandates it should assess. For many toxicants, there is still insufficient information to set water quality standards.

Toxicants such as endocrine disruptors and pharmaceuticals are a concern though little is known about their effects on fish populations and aquatic communities. Endocrine disrupting compounds have been found in many Minnesota waterways and changes in the physiology of fish have been noted at several of these sites. Laboratory studies at the University of Minnesota found that reproductive behavior of exposed fish is affected. But we don't know if such individual fish effects have depressed fish populations in Minnesota waters. A recent experimental exposure of fish to endocrine disrupters in a Canadian lake did lead to near disappearance of fathead minnows, an important food for game fish and a popular bait species. Pharmaceuticals have also been found in many Minnesota waters, but their direct effects on fish are understood even less than those of endocrine disrupting compounds.

Temperature

Fish and aquatic invertebrates are cold-blooded, so their growth and reproduction are greatly controlled by temperature. As temperature increases, so does fish activity, demand for food and need for oxygen. Fish communities can be divided into three groups based on the summer maximum temperatures each can tolerate: coldwater, cool water and warm water. Thus, summer water temperatures often determine the fish community supported in a lake or stream, such as coldwater trout communities, cool water walleye-perch communities, and warm water bass-panfish communities (see Figure 1, page 76). Human activities that alter water temperatures can lead to short-term or more widespread and persistent harm to fish communities. Sudden, local changes in water temperatures can be lethal, such as the fish kill associated with the abrupt shutdown of the Monticello Nuclear Power Plant in winter 2007. Such instances are well regulated and failures of compliance should have only short-term, localized, impacts on fish communities. Land use changes, such as the removal of riparian vegetation associated with agriculture or riparian forest harvesting, are more widespread and can elevate stream temperatures beyond the tolerance levels of coldwater fish. These changes can eliminate certain species, such as brook trout, and prevent their restoration until riparian vegetation and thus a cooler summer water temperature is re-established.

Climate change now poses the greatest threat to suitable water temperatures for fish communities in streams and lakes. Increased temperatures associated with climate change will results in the loss of suitable stream habitat for trout in a number of streams in Minnesota. Researchers at the University of Minnesota indicate that suitable lake habitat for coldwater fish communities will be reduced by 45%. An example of how these communities might unravel, mentioned in the discussion of dissolved oxygen, is through the loss of lake herring that provide food for large lake trout, walleye and northern pike in coldwater lakes. Suitable habitat for coolwater communities will be reduced in more southern shallow and moderate depth lakes, and will increase in northern lakes at the expense of coldwater communities. Habitat for warmwater fish communities will increase, facilitating a major expansion of warmwater fish populations.

Temperature changes due to climate change will increase the effects of other stressors, such as dissolved oxygen (which is also exacerbated by nutrient loading), riparian vegetation loss, and invasive species. Warmer temperatures will potentially allow many invasive species to expand their ranges into and within Minnesota. Asian carp could be able to expand their range and number, and invasive plants such as hydrilla will find a more suitable climate in the state. Fish not currently considered invasive, such as smallmouth bass, will be able to expand their range and likely alter coldwater fish communities. Integrative research is needed to refine and test predictions of fish community changes due to climate change combined with other drivers, such as nutrients, habitat degradation and invasive species.

Hydrologic Modification

Ditching and drainage tiles, dams, and water-level regulation have modified the hydrology of the Minnesota landscape over the past two centuries. Perhaps the most extensive modification was caused by building drainage systems, ditches and tiles, for agriculture in western Minnesota. This type of drainage has transformed nutrient cycling and hydrologic dynamics, including changes in structure, function, quantity and configuration of stream and wetland ecosystems. Straightening and deepening of natural channels to build drainage ditches degraded habitat for fish and other aquatic organisms by altering floodplain and riparian connectivity, and sediment dynamics. Large-scale conversion of an original checkerboard of wetlands into linear systems resulted from connecting formerly isolated wetland basins to extensive drainage networks and constructing main channel ditches through millions of acres of formerly low-lying marsh or wet prairie. This conversion reduced surface water storage, increased water movement, and concentrated water into main channels. The result was increased flows and flooding in larger streams and rivers. Cumulative changes in hydrology, geomorphology, nutrient cycling, and sediment dynamics have contributed to the decline of aquatic communities including fish, waterfowl, and other aquatic wildlife.

Strategies to reduce negative effects of drainage ditches and tiles on aquatic ecosystems vary widely in their effectiveness as well as their contemporary economic and political feasibility. Minnesota needs multiple strategies to mitigate the undesirable effects of altered hydrology on aquatic ecosystems including fish communities. These include changes to cropping systems and nutrient management, off-site wetland and riparian habitat protection, and restoration in critical areas across the landscape.

Lowhead dams dot Minnesota's landscape and block fish migrations to spawning areas. For example, a series of dams built in the early 1900s disconnected the Red River into segments and disrupted migrations of lake sturgeon and other fish. Today, we know it is possible to reconnect the river by employing a technique developed by Luther Aadland of the Minnesota DNR. In one demonstration, the Riverside Dam at East Grand Forks was modified from a low-head dam into a gently sloping bed of rocks. It still functions as a dam, but new pools and eddies formed by the rocks provide habitat for walleyes, channel catfish, and other fish. The fish now have access to miles of habitat formerly blocked by the old dam.

Water-level regulation of reservoirs can change lake dynamics in ways that harm fish populations. Shoals

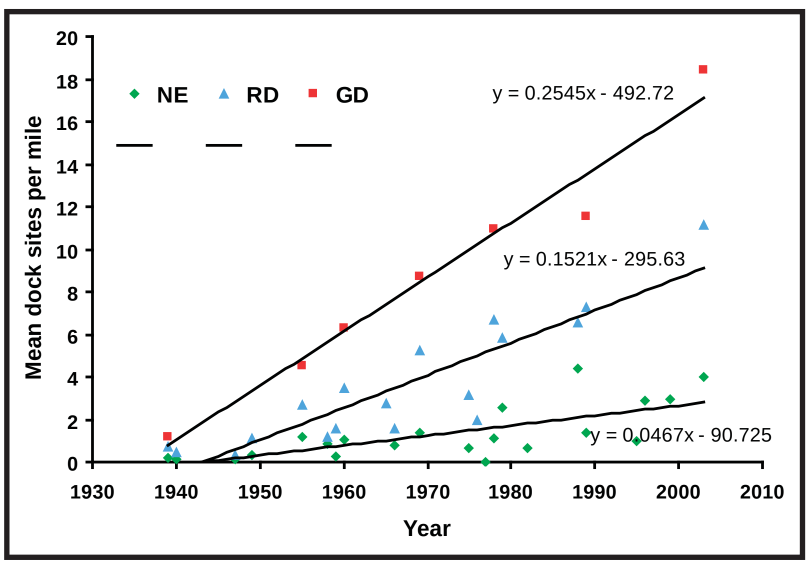

Figure 8: Development around north-central Minnesota lakes, as dock sites per mile, from DNR aerial photos. General development (GD) lakes have a faster rate of development than recreational development (RD) lakes, whereas natural environment (NE) lakes are just beginning to be developed. In 2003, mean development density was 18.5 homes per mile for GD lakes, 11.2 homes per mile for RD lakes, and 4.0 homes per mile for NE lakes. Credit: Paul Radomski, Minnesota DNR.

used by fish and aquatic plants may be exposed or inundated and nutrient cycles modified. For example water level fluctuations affected the commercial catch of walleye on Namakan Lake and Rainy Lake. Plans for regulation of water levels need to assess and reduce potential harms to fish communities.

Aquatic Habitat Degradation and Loss

Shoreland developments are changing Minnesota's lake ecosystems. Development pressure is increasing with more dwellings and docks per lake each year (see Figure 8, facing page) in Minnesota that has led to a cumulative effect on fish habitat.

Shoreline habitat losses include removal of downed trees, aquatic vegetation, and the removal of riparian wetlands. Shoreline alterations include planting riprap, constructing walls and planting sod to the waters edge. A recent study documented aquatic vegetation losses, an important component of shoreline habitat, from 1939 to 2003 in Minnesota lakes (see Figure 9). It is estimated that between 20 to 28 percent of the near-shore emergent and floating-leaf coverage has been lost due to development in bass and walleye lakes. On average there is a 66 percent reduction in aquatic vegetation coverage with shoreland development. These declines in aquatic vegetation coincide with lower fish production in lakes. Woody habitat losses are also occurring in Minnesota lakes but have not been quantified. Studies in other states give some insight: researchers found less submerged woody habitat from fallen trees along developed shorelines in Wisconsin and Michigan, and predicted that recent losses would affect fish communities for centuries.

Not all shorelines are created equal. This is true both for people and fish. For many of us, the perfect lakeshore has a gentle slope, clean and clear water, a sand beach with no aquatic vegetation, and a reasonable distance to deep water for boat access. Lakeshore lots with these characteristics command a high price. Fish have no regard for our economics and do not generally share our shoreline preferences.

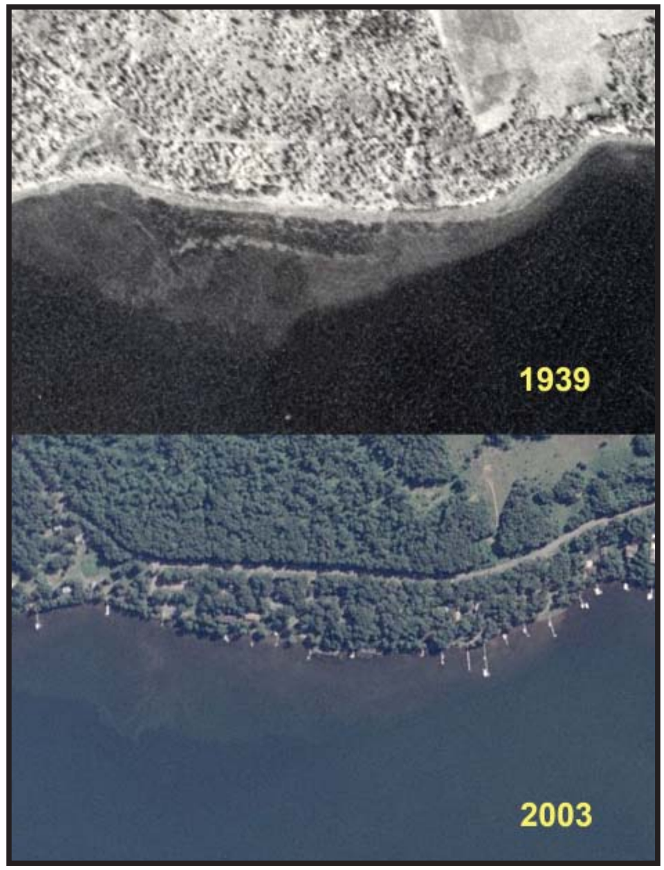

Figure 9: Aerial photographs show the same shore of a Minnesota lake 64 years apart. Note the disappearance of aquatic vegetation along the lakeshore in the 2003 photo. Credit: 1939: U.S. Department of Agriculture, 2003: U.S. Department of Agriculture, Farm Service Agency.

Clean water is important to fish but they need more than water just as birds need more than air. Floating-leaf and emergent vegetation assures a good food supply for fish because one of their main foods, aquatic invertebrates, use the vegetation as habitat. Many fish depend on aquatic vegetation and the shoreline to provide spawning habitat, cover, and refuge from predators. While sought after by humans, a sand beach is unsuitable habitat for many fish species. Walleyes, for example, select clean, wave-washed gravel and cobble shorelines for spawning. Near-shore dredging and adding sand for beaches damages walleye spawning areas.

Human activities that change shoreline habitat can alter ecological processes and energy flow within lakes, thereby reducing their ability to support diverse and healthy fish communities. Intact, undisturbed shorelines provide many environmental benefits to our lakes and rivers, such as absorbing nutrients that reduce water quality, reducing erosion from waves and current and defining the high ecological qualities of our state.

There are three major knowledge gaps about shoreline habitat loss in Minnesota. First, the extent of and the ecological consequences of removal of fallen trees from lakes are poorly understood. Second, a better understanding is needed of the rate of dock development, size of in-water structures, and associated impact on aquatic habitats and fisheries production. A couple facts illustrate the importance of this issue. Average dock size has increased 51 percent from 1978 to 2003; and an estimated 20 percent of the shoreline in Crow Wing County was affected by docks in 2003. Finally, research on shoreline habitat protection and restoration with regard to social and economic barriers and incentives is also needed.

Stocking

Fish stocking can provide many economic, social and conservation benefits, but can also harm fish communities. Stocking has introduced new species, enhanced existing populations, and rehabilitated depleted or locally extinct populations. Stocking fish in Minnesota began in the 19th century with the introduction of the now-reviled common carp and the more appreciated brown trout and steelhead. Among a dozen species stocked presently, walleye alone are stocked into about 950 lakes. Economic benefits of sport fishing are enhanced by the reality or perception of improved fishing due to stocking. Many of Minnesota's current fisheries would not exist without stocking. For example, many southern lakes now contain walleye where conditions are poor for their natural reproduction and urban ponds now contain hybrid tiger muskie, splake, and catfish. Inappropriate stocking can cause ecological harm through introduction of new species that disrupt the existing fish communities. It can also alter genetic diversity when stocked fish interbreed with native fish and it can introduce diseases carried by the stocked fish.

Minnesota provides many examples of positive, negative, and mixed outcomes of stocking. Stocking has established non-native species, including rainbow trout, brown trout and carp. Although many view brown trout stocking as a success story, studies indicate these fish may limit the production of brook trout, the native species. Stocking has helped rehabilitate depleted populations such as lake trout in Lake Superior and walleye in Red Lakes. In Upper and Lower Red Lake, three recent large stocking events over five years were so successful that the fish population recovered enough to resume fishing only eight years after a complete closure.

Many attempts to increase fish abundance through stocking have been unsuccessful, and potentially caused harm. In decades past, many brook trout originating from the eastern U.S. were stocked widely in southeastern Minnesota streams. Recent genetic data found no descendants of these eastern fish in the tested brook trout populations. But we don't know how many populations experienced declines from continuous stocking of these genetically unfit brook trout. Effects of genetically unfit fish were documented along the North Shore of Lake Superior, where naturalized steelhead (migratory rainbow trout) were shown to have much higher survival than a stocked rainbow trout strain. Mating with stocked trout drastically reduced the survival of the hybrid offspring. In the Minnesota muskie program, three decades of stocking a Shoepack strain turned out counterproductive to maintaining a trophy fishery. The DNR discontinued stocking the Shoepack strain when they were found to have less genetic potential for growth than other muskie strains. Unfortunately, new genetic data show that Shoepack genes still persist and affect growth in some populations twenty years after stocking ended. Fish stocking is ubiquitous in Minnesota but generally lacks direct monitoring of its consequences. This makes it hard to distinguish positive and negative effects statewide and thus to wisely direct funds and, as appropriate to improve practices for stocking.

The Fishery

Minnesota has long been known for the exceptional quality of its recreational fisheries of walleye and northern pike, but largemouth bass, crappie, sunfish, and trout are also well regulated. Fish populations respond to the removal of individual fish, by any fishing method, by increasing the growth rates of those not caught. This is a "density-dependent" response where the exploited fish populations "compensate" for the individuals removed by changes in their biological characteristics. In previously unfished stock, the removal of fish (catch) within a very few years, will cause a temporary reduction in numbers of fish, average size, average age, and mean age of first spawning. If the fishing pressure continues or intensifies only moderately, after a few generations, the increased growth rate often results in a greater abundance of fish, a narrowing of size and age distributions, and an increase in reproduction. When this occurs, the population is said to have come into "equilibrium" with the fishery, and may endure for many years without showing major changes in catch rate (expressed as Catch Per Unit of Effort, or, CPUE). If the fishery increases in intensity, fish may reach their maximum biological growth capacity and attain maturity at their minimum spawning age and size. In this condition, the population may experience sudden changes in numbers or reproductive capacity due to relatively minor changes in fishing pressure or environmental quality. This vulnerability often increases year-to-year variability of populations that had previously been stable. Immediate reductions of fishing effort may not immediately restore the fisheries to a stable pattern of production. Fishing can induce these changes without other stresses acting upon a population, but these effects are often exacerbated and sometimes masked by the confounding effects of changes in water quality and the introduction or invasion of non-native species.

Minnesota's fisheries have gone through three distinct phases:

- The pre-settlement Native American fisheries
- Early Euro-American settlement up to World War II
- The post-WWII era

The first phase almost certainly existed in equilibrium between human and fish populations with many species caught and consumed at sites of opportunity. Changes in productivity were likely small or modest, with little alteration of physical or biological characteristics of watersheds. Fisheries in the second phase declined in quantity and quality in response to rapidly increasing human densities and changes in forest cover and prairie agriculture. During this time, fisheries were predominantly used as a supplemental food resource and secondarily as a recreational resource. In the third phase, including contemporary times, virtually all of Minnesota's fishery resources are being subjected to at least a modest level of exploitation. During this period, many important stocks of recreationally valuable species have declined in individual body size and abundance (low CPUE) and have experienced widely variable year-class strength. In the future, additional fisheries management controls and surveillance will be required to protect, maintain and restore high-quality fisheries. Effective management of fishing and stocking can only go so far to achieve high quality fishing. In order to maintain and improve fish communities, Minnesota must reduce cumulative effects of the more pressing drivers of change, discussed above, to assure quality fishing for future generations.

Major Data Gaps for Minnesota Fish Resources

The fish team has identified a number of major data gaps that impede efforts to sustain or restore the quantity and quality of fish communities in Minnesota's lakes and rivers.

1. Invasive Species - Much better tools are needed to predict, prevent, reduce and manage the harmful effects of aquatic invasive species. An urgent issue is preventing the spread of a devastating new fish virus. Statewide data are missing on total public and private annual expenditures to control aquatic invasive species and economic value of harm they cause.

Explanation: Research is needed on species-specific control methods and tools to evaluate the effectiveness of current management strategies. Also needed are better methods for risk assessment of new invaders to determine their potential adverse effects on native species, outdoor recreation, and other natural resources. There is very little known about the total economic impact in Minnesota related to aquatic invasive species. Control and management of them is thought to be extensive.

We lack ways to reduce mortalities from a destructive fish viral disease that will likely arrive soon in Minnesota. Called viral hemorrhagic septicemia (VHS), this disease has caused large fish kills in the lower Great Lakes and is spreading westward to Minnesota. Many Minnesota fish species are vulnerable including prime sport fish such as walleye, muskies, northern pike, trout and bass. Once it arrives in Minnesota, reducing the spread of VHS within the state will be a major challenge.

2. Land Disturbance - How much land disturbance can occur before there is a negative impact on fish communities?

Explanation: Scientific information indicates that increased land disturbance is correlated with degradation of fish communities but fisheries managers need a predictive tool to help quantify and manage. A predictive tool would make it possible to quantify tolerable types and amounts of disturbance in shorelines, stream banks and uplands. A more sophisticated predictive model would help to assess cumulative impacts of all disturbances within an entire watershed rather than dealing with each lake or stream in a piecemeal fashion. Baseline data is needed on normal sediment loads in rivers that still have high water quality. These data will inform the design of effective policies to prevent increases in sediment pollution due to future land use changes in these watersheds. The collection of sediment samples could be added to existing stream monitoring programs in Minnesota.

3. Aquatic Habitat Loss - How much aquatic habitat can be lost in lakes before harming the productivity of fish populations? What are effective social and economic incentives for shoreline habitat protection and restoration?

Explanation: This question refers to habitat provided by floating and emergent plants, woody material and other natural structures within different kinds of lakes. Although scientists can reasonably predict the minimum habitat needed for productive trout populations in streams, data gaps make it impossible to do the same for most fish species in lakes. It would be most helpful to develop a predictive tool to answer questions such as: how much dock development can occur without degrading the fish community in a lake?

Good data on major incentives and barriers to get people to protect shoreline habitat would inform the design of effective policies to prevent additional shoreline changes and restore shoreline habitat for heavily impacted lakes and rivers. This will require social science research linked to development of feasible policy options.

4. Climate Change - How will climate change affect fish communities in Minnesota, especially how it will exacerbate effects of existing stressors? Addressing this question requires filling major baseline data gaps and restarting bathymetry mapping of Minnesota lakes.

Explanation: Some human-caused climate change is now irreversible and the state needs to anticipate how it will affect our fish communities. This irreversible level of climate change will exacerbate land use changes and the other major drivers of change to aquatic habitats and aquatic food chains that already harm fish in Minnesota. Decision makers need reliable predictions of effects of climate change on fish communities, which take into account interactions with other drivers of change. This requires integrated quantitative analyses that compare lightly stressed with heavily stressed lakes and incorporate data on surface water quality, groundwater, the aquatic food chain and all fish species. In turn, this requires filling key data gaps, such as information on non-game fish (there is better data on game fish), natural foods of fish (zooplankton and invertebrates), and more comprehensive data on lake temperatures and water levels. Accurate data on lake bottom depths and contours are also needed. This requires restarting lake mapping surveys by the DNR, which were recently stopped due to lack of funding. Finally, better compilation of existing data is needed, building on ongoing efforts such as integration of aquatic plant databases.

5. Fish Stocking - What are the overall effects of fish stocking on anglers' fishing experience, the target species, and fish communities?

Explanation: The state lacks comprehensive data on which fish stocking programs lead to a net increase in the quality and quantity of fish caught by anglers and which ones do not provide measurable benefits or cause harm. Existing data cover only a few species in a few bodies of water or over a relatively short time frame. We also lack information on genetic effects of stocking, except for a few recent studies. Two important genetic data gaps are whether stocked fish are genetically fit or unfit to thrive in the receiving lake or river and whether fish stocking erodes genetic diversity of wild populations of the same species. Genetic diversity is the 'principal' in nature's bank that will generate long-term, high 'interest' rates -- productive fish populations far into the future. The coming climate change makes it more important than ever to protect genetic diversity in our wild fish populations. Finally, virtually nothing is known about when stocked fish have positive, negative or neutral ecological effects on the entire fish community in the stocked habitat.

6. Endocrinal Pharmaceuticals - We do not know whether endocrine disrupters and pharmaceuticals in the sanitary waste stream are harming the productivity of fish populations. Also, we lack the data required to set water quality standards for impacts of most contaminants on entire fish communities.

Explanation: We need more comprehensive information on the distribution of endocrine disruptors and pharmaceuticals in Minnesota waters and whether they affect fish health and entire aquatic communities. Although we know how some long-existing contaminants affect individual fish, we don't know how they affect aquatic communities as a whole and whether existing water quality standards need to be modified based on community impacts. Little is known about whether contaminants erode genetic diversity in wild fish populations.

Figure 10: Happiness on Mille Lacs.
Credit: John Cannon, University of Minnesota.

"A big reason I live here is...the fishing."
— Minnesota 2050 Project participant