Stresses and Threats to Natural Resources of Michigan Lakes

Human development for commercial, agricultural, residential, and recreational purposes occurs throughout our landscape, along shorelines, and within lakes and wetlands. Alterations of natural conditions can be minor to very extensive within any specific watershed. Changes from human development have been occurring in Michigan for over 150 years. Accumulation of many small changes over this time period has led to completely altered landscapes, and people often do not have a clear understanding of a lake or its watershed's natural condition. Watersheds are complex and function as ecological units, so changes in one part of the system often have widespread or cascading effects on the entire system (Schindler and Scheuerell 2002).

Alterations that almost always have whole-lake affects include changes in the uplands of the watershed; particularly artificial drainage systems, removal of wetlands, fertilization practices, use of pesticides and other chemicals; construction and operation of lake-level control structures; introduction of non-indigenous species; and shoreline development by people. Drainage, removal of wetlands, fertilization, and chemical use affects the quantity and quality of water lakes receive. Drainage increases the flow of water over the surface of the land, resulting in increased erosion of sediment, and increased nutrient and chemical runoff. Historically, wetlands naturally provided filtering of nutrients and sediment from runoff, but these buffers have largely been removed from our landscape, especially in southern Michigan. Fertilization for agriculture has significantly increased nutrient content in our soils, surface waters and ground waters. Residential, industrial and agricultural use of pesticides increases pollutant runoff into our lakes. Increased erosion of sediment causes accelerated filling of our lakes. Increased nutrients cause eutrophication. More eutrophic lakes generally have higher levels of algae in the water column, resulting in decreased clarity and light penetration and changes in algal species. Reduced light penetration results in lower aquatic macrophyte growth. Increased deposition of organic matter results in oxygen depletion in the hypolimnion, and increased nutrient recycling within the lake. Nutrients in the bottom sediments eventually build up and contribute to increased in-lake nutrient recycling or increased growth of macrophytes. All of these factors affect habitat requirements of aquatic organisms. Shoreline development and direct removal of aquatic macrophytes reduces habitat for animals living within the lake and along its borders. Habitat degradation disrupts the ecological integrity of the system, affecting species composition, distribution, and abundance of animal resources.

Cumulative Effects of Small Modifications to Habitat

Resource professionals have known for many years that within lake watersheds, small changes to habitat accumulate and have detrimental affects on natural resources at various scales. Burns (1991) summarized the American Fisheries Societies concerns with cumulative effects of small modifications to habitat, indicating that resulting changes not only have local effects, but also watershed, regional, oceanic, and global scale effects. They should therefore be evaluated and viewed from those perspectives. Cumulative effects result from complex relationships among spatial, temporal, and compositional changes made to the habitat of any species or biological community. The American Fisheries Society considered this issue important enough to establish a resource policy on cumulative effects of small modifications to habitat (Rasmussen 1997).

Within Michigan, both the Great Lakes and the majority of inland lakes have experienced substantial cumulative alteration of natural habitat. Fisheries resources of the Great Lakes have been severely altered from original conditions prior to European settlement, including changes in dominant fish species, extinction of species, and declines in overall productivity (Smith 1970). These changes resulted from the accumulation of numerous human-induced alterations including, introduction of exotic species by barrier removal, overfishing, dam construction across tributaries, deforestation of the landscape, artificial drainage, wetland losses, nutrient pollution, and chemical pollution. These were coupled with lack of inter-jurisdictional resource management, inappropriate laws, and political neglect regarding natural resources. Some of these issues, like cooperative resource management and overfishing are less important today, but many of these problems continue.

A number of recent studies document the cumulative effects of small modifications to habitat on biological communities resulting from human lakeshore development in north temperate lakes. Deadwood (coarse woody debris) is a habitat component of north temperate lakes that is produced immediately adjacent to lake shorelines or streams flowing into lakes. The ecological function of deadwood is not as well known in lakes as in streams, but it does provide an important substrate for plants and animals in the littoral zone of lakes (Bowen et al. 1995; France 1997), provides spawning habitat for fish, serves as cover and a predation refuge for fish (Hanson and Margenau 1992; Rust et al. 2002), may provide a significant amount of dissolved organic carbon, and protects shorelines from wind and ice erosion. Guyette and Cole (1999), found that eastern white pine logs were very persistent in Swan Lake, Ontario, dating from calendar years 982–1893. Accelerated inputs of deadwood occurred during the late nineteenth century logging period, but little had fallen into the lake during the past 100 years. Most (79%) of the eastern white pine in the lake had drifted from the original position to other areas of the lake consistent with prevailing winds. Eastern white pine may float for many centuries and be moved by wind and ice formations.

Christensen et al. (1996b) found that deadwood was significantly greater in undeveloped lakes than in developed lakes in northern Wisconsin and Michigan. Deadwood found within the lake was positively correlated with levels of riparian tree density and negatively correlated with cabin density. The strength of the statistical relationship between riparian tree density and deadwood in the lake was dependant on the spatial scale at which it was measured. Lakewide analyses produced stronger statistical correlations than analyses at the smaller spatial scale of individual sampling plots. Dwelling densities ranged from 0 to 40/mi of shoreline. Overall, there was significantly more deadwood (logs 2 inches and greater in diameter) in undeveloped lakes (mean = 893/mi of shoreline) than in developed lakes (mean forested = 610/mi of shoreline, cabin occupied = 92/mi of shoreline). Regression analyses indicated densities of deadwood logs in undeveloped lakes ranged from 470 to 1,545/mi of shoreline. Predicted dwelling densities corresponding to these log densities were 0.3–7.5/mi of shoreline. Densities of shoreline trees (including dead trees) within 33 ft of the shoreline (normal drop distance to water) at undeveloped lakes ranged from 363 to 1,017/acre. Based on these observations, Christiansen et al. (1996) estimated that losses of deadwood resulting from development of the shoreline will affect the littoral communities of lakes for about 2 centuries.

Radomski and Geoman (2001) found that developed shorelines had substantially less emergent and floating-leaf vegetation than undeveloped shorelines in Minnesota lakes. Developed shorelines averaged 66% less vegetative cover relative to undeveloped shorelines. Overall, loss of vegetation in centrarchid-walleye lakes was estimated at 20–28% based on present housing densities, and projected losses for 2010 may be as high as 45% based on lakeshore housing growth estimates. Significant aquatic vegetation losses were visible at dwelling densities of 9.6/mi. Both biomass and mean size of northern pike, bluegill, and pumpkinseed were correlated with emergent and floating-leaf vegetation. Biomass and mean size of fish were positively correlated with increasing vegetation coverage, with the exception of mean size for northern pike.

Rust et al. (2002) evaluated lake characteristics influencing spawning success of muskellunge in northern Wisconsin lakes. The most important characteristics found were human development of the shoreline; amount of deadwood per mile of shoreline and percentage covering spawning habitat; natural seasonal water level fluctuations; and amount of soft, organic, nitrogen-rich sediment. Lakes with self-sustaining muskellunge populations were mostly surrounded by forest, whereas lakes that required stocking had less shoreline in a natural state and more human development.

Bryan and Scarnecchia (1992) evaluated species richness, composition, and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of Iowa's 6,000-acre Spirit Lake. Young-of-the-year fish communities in naturally vegetated sites were compared with those inhabiting nearby sites where lakeshore development (i.e., homes, boat docks, and beaches) reduced nearshore macrophyte species richness and abundance. Plant species found in natural sites were similar to those found in Michigan lakes (dominated by *Potamogeton* spp.). Emergent vegetation (e.g., *Schoenoplectus acutus* and *Typha* spp.) was absent from developed sites. Species richness and total fish abundance were consistently greater in natural sites compared to developed sites in both nearshore (0–1m) and intermediate (1–2m) depth zones, but differed little between natural and developed sites in the offshore (2–3m) zone. Nearly 50% of the species sampled, including yellow perch and bluegill, inhabited limnetic areas as larvae before migrating inshore as juveniles. Eighteen of the twenty species collected as juveniles were greater in abundance in natural sites compared to developed sites. Smallmouth bass and darters were found in equal or greater abundance in developed sites. Longnose gar, northern pike, yellow bullhead, banded killifish, green sunfish, black crappie, yellow perch, largemouth bass, bluegill, spottail shiner, bluntnose minnow, and black bullhead were scarce or absent from developed sites.

Schindler et al. (2000) evaluated patterns of fish growth along a residential development gradient in north temperate lakes. Bluegill and largemouth bass growth was studied in 14 lakes located in northern Wisconsin and northern Michigan. Size-specific growth rates for both species were negatively correlated with the degree of lakeshore development, although this trend was not statistically significant for largemouth bass. On average, annual growth rates for bluegill were 2.6 times lower in heavily developed lakes than in undeveloped lakes. Bluegill populations were approximately 2.3 times less productive in highly developed lakes than in undeveloped lakes. They concluded that extensive residential development of lakeshores may reduce the fish production capacity of aquatic ecosystems. Study lakes and dwelling densities (0–40/mi) were the same as Christensen et al. (1996b).

Jennings et al. (1999) evaluated the basin-wide and local effects of cumulative habitat modifications in Wisconsin lakes. By evaluating an index of lake trophic status (cumulative phosphorus increases over time), they were able to show a shift in the fish species assemblage with increasing phosphorus levels. Intolerant species became less abundant and tolerant species more abundant on a lake-wide level. Fish species richness comparisons were made between natural shorelines, vertical seawalls, and rip-rap. Species richness was greatest at sites with rip-rap followed by natural shorelines. However, this information has a different ecological meaning when viewed from a larger spatial scale. Although rip-rap increased structural complexity at the scale of the individual site, when viewed at the scale of the whole lake, conversion of the entire shoreline to this one habitat type would not increase habitat diversity, but cause a reduction. Thus, conversion of unaltered shorelines to rip-rap should not be viewed as an enhancement. But rip-rap provides better fisheries habitat than retaining walls when erosion control is a necessity. Both spatial and temporal scales were important in evaluating the effects of cumulative habitat modifications in these Wisconsin lakes.

Jennings et al. (1999) discussed the implications of habitat alteration in relation to regulatory programs and public perception. Most alterations of littoral zone habitat in central North America are incremental and cumulative, occurring primarily at the spatial scale of individual recreational and residential properties. Many heavily affected lakes in this region did not undergo single large, drastic alterations but were subject to numerous small modifications to structural components of habitat and gradual shifts in land use. This study demonstrated that local habitat modifications lead to small changes in local species richness, but more importantly, assemblage structure responds at larger spatial scales, when many diverse incremental changes have occurred within a basin over time. Regulatory programs designed to protect ecosystem function by conserving small fragments have merit, even if local responses to small changes are not immediately measurable. Biologically, the objective is to maintain ecosystem function at the landscape scale, but the regulatory tools apply to small shoreline fragments that are often incorrectly perceived to be ecologically insignificant.

Woodford and Meyer (2003) evaluated the impact of lakeshore development on green frog abundance in 24 northern Wisconsin lakes. Green frogs are a shoreline-dependent species that inhabit nearly all types of permanent water in the region studied, establish and defend distinct territories, and tend to remain along the periphery of lakes and ponds throughout the summer breeding season. Adult green frog populations were significantly lower in lakes with developed shorelines (average dwelling densities = 20.9/mi) than lakes with little or no development (average dwelling density = 2.9/mi). Suitable habitat, rather than development density, was the primary factor affecting adult frog abundance. Greater development densities significantly decrease breeding habitat quality, resulting in lower adult frog abundance. Adult green frog densities ranged from 1.6 to 106.2/mi of lake perimeter. Wisconsin has regulations that limit the maximum development density surrounding lakes to 53.1 homes or cottages per mile of shoreline. Woodford and Meyer (2003) estimate if a Wisconsin lake was developed to its regulatory potential, less than 50% of suitable shoreline habitat would remain and the local green frog population would disappear. Their findings suggest current regulations and enforcement are not protecting the shoreline habitat that is crucial to sensitive amphibian populations in Wisconsin.

Lindsay et al. (2002) studied the influence of lakeshore development on breeding bird communities in a mixed northern forest. Thirty-four paired lakes were studied for breeding birds in lacustrine habitats of northern Wisconsin. Significant differences were not found between developed and undeveloped lakes in bird abundance, richness, or species diversity. Significant declines in the prevalence of insectivorous and ground nesting birds were documented on developed lakes, contrasting with increased prevalence of seed-eating birds and deciduous-tree nesting birds. Changes in diet guild diversity appeared to occur near a development threshold of 4.8–6.5 dwellings per mile of shoreline.

All of the recent studies evaluating effects of human development on lakeshores and lake watersheds indicate long-term cumulative ecological degradation of natural lake communities. It is essential that biologists define the appropriate spatial, temporal, and component scales to evaluate the effects of cumulative habitat modifications within our lake ecosystems. Cumulative habitat effects must be considered in all lake management activities.

Artificial Drainage

Artificial drainage includes establishment of legal drains, road drains, agricultural drains and field runoff, urban stormwater drains and runoff, and residential drains. Artificial drainage changes the pattern of water flow from groundwater seepage to surface water runoff. Increased surface water runoff increases nutrient, sediment, and chemical pollutant discharge into lakes. This degrades water quality conditions in lakes and generally affects the entire lake, often dramatically.

Drainage often is established in areas with high groundwater tables, so it is often directed at removing wetlands. This removes the natural filtering capacity of wetlands resulting in even more pollutants reaching lakes. Historical losses of wetlands in Michigan have been estimated as high as 70%. Wetland losses continue, although in recent years the rate of loss has diminished.

Water Temperature and Dissolved Oxygen

Water temperature and dissolved oxygen are critical habitat components for aquatic organisms. Generally, direct effects from human activities on these components are relatively limited. Some large industrial discharges can have significant effects. More often, human activities indirectly affect water temperature and dissolved oxygen. All activities affecting trophic status, especially nutrient (fertilizers, septic tanks) and organic carbon contributions, can have effects on dissolved oxygen levels. Vegetation control programs can affect both water temperature and dissolved oxygen levels (refer to *Vegetation control and Swimmer's Itch control*)**.**

Nutrient, Pesticide, and Chemical Pollutants

Nutrient and pesticide use occurs in both agricultural areas for crops and residential areas for lawns. Chemical pollutants come from industrial discharges, urban street runoff, and improper disposal from residential areas. Nutrient increases result in eutrophication that usually affects the entire lake. Moderate to highly eutrophic lakes generally have high algal abundance in the water column, resulting in decreased clarity, light penetration, and changes in algal species. Reduced light penetration results in lower aquatic macrophyte growth. Increased deposition of organic matter results in oxygen depletion in the hypolimnion, and increased nutrient recycling within the lake. Nutrients in the bottom sediments eventually build up and contribute to increased in-lake nutrient recycling. All of these factors affect the basic habitat of aquatic organisms. Pesticide and other chemicals can directly affect the health of biological organisms using the lake, and also result in human health effects.

Nutrient runoff from upland activities such as agriculture or lawn maintenance can also negatively affect Great Lakes coastal wetlands. High levels of nitrate and phosphorus favor exotic or invasive plant species, such as purple loosestrife and giant reed *Phragmites*, over native species and at high levels can actually prevent the establishment and growth of plants. Few comprehensive water quality investigations have been conducted, and measurements in the coastal wetlands are rare.

Dams and Lake-Level Control

Lake-level control structures are used to establish and maintain abnormally high lake levels (usually during open water periods), and low (nearer natural) lake levels during periods of ice cover. The stable, high water levels are favored by lakeshore residents for boating, and low levels prevent ice damage to docks and lawns. Legal lake levels are established under P.A. 451, Natural Resources and Environmental Protection Act, Part 307, Inland Lake Levels. Augmentation wells also can be used to maintain artificially high water levels in lakes.

Lake-level control with structures or augmentation wells can have significant effects on entire lake ecosystems, especially in relation to shoreline areas of the lake, fish spawning, fish movements, community diversity, and plant and animal production (Wilcox and Meeker 1992). Dams prevent normal movements of fish in and out of the lake for seasonal habitat needs. They alter natural water fluctuations necessary for maintaining diverse and productive wetland plant communities, and nesting and rearing habitat for fish, mammals and water birds. They also increase shoreline erosion by maintaining high water levels. This generally leads to the construction of seawalls to prevent erosion. Seawalls prevent normal shoreline movements of amphibians and mammals, reduce natural shoreline vegetation, reduce emergent vegetation, and increase erosion of other shoreline areas because wave energy is not dissipated properly on seawalls and is transferred to other shoreline areas.

Extended artificial high water levels can severely alter or eliminate specific plant communities by creating unfavorable habitat conditions. The periodic drying of shoreline wetlands is important to allow the soils to aerate, to accelerate decomposition of detritus, and to facilitate nutrient exchange.

Wetlands are typically more productive (plant vigor, aquatic invertebrate abundance, and wildlife diversity) following periods of dryness. Seasonal, annual, and multiple-year drought periods have been part of the natural cycle and ecosystem processes of Michigan lakes for thousands of years. Unnatural water manipulations affect ecosystem integrity of both the Great Lakes and inland lakes.

Recreational and hydroelectric dams prevent fish movements into lakes and the natural downstream movement of deadwood. This is of particular concern for the Great Lakes where deadwood inputs to tributary streams have been significantly reduced since the early to late 1800s. Great Lakes fish movements, spawning, and recruitment are also impaired by dams.

Non-indigenous Species

There are presently 209 known, non-indigenous plants and animals that have been introduced into the Great Lakes basin between 1800 and 1999, of which 77% (162) are aquatic species (Harrison 2003). Routes of entry into the Great Lakes basin include ballast water from ships, canals, roadways and railways, intentional and unintentional releases, and many unknown sources. The introduction or invasion of exotic species can result in significant changes that usually affect the entire lake. Non-indigenous species that have been present for many years in our lakes include alewife, sea lamprey, common carp, goldfish, and rainbow smelt. These species have caused significant changes in both Great lakes and inland lake aquatic communities.

Species that presently are invading many lake systems include zebra mussels *Dreissena polymorpha*, curly-leaf pondweed, Eurasian water-milfoil, purple loosestrife, *Phragmites*, gobies, ruffe, various micro-invertebrate zooplankton (*Bythotrephes cederstroemi*, *Cercopagis pengoi*, *Daphnia lumholtzi*), rusty crayfish, and many others. Of particular note, curly-leaf pondweed and Eurasian water–milfoil are plant species that have spread rapidly throughout Michigan and have moderate to extreme effects on native submersed plant communities. These plants have aggressive growth habits and sometimes will completely dominate plant communities causing losses of native plants (Boylen et al. 1999). They also can grow in very dense mats to the surface of the water and are often considered to be a nuisance to some recreational activities. When these species dominate the plant community, they provide less valuable habitat than native plants (Savino and Stein 1982; Keast 1984; Savino and Stein 1989; Smith 1993). They can also coexist in plant communities without significant effects on the ecosystem (Barko et al. 1994), especially if native plants are diverse, healthy, and undisturbed. In contrast, control programs may sustain non-indigenous species for a greater number of years than would occur without management activities (Chambers et al. 1994). This may be related to the failure of controlled plant beds to develop an herbivore community, and the ability of aggressive exotic species to expand into areas devoid of vegetation resulting from control programs.

Generally, invasive plants become established and grow more extensively in water bodies that have intensive human use and development (Nichols 1994). Heavy use of a lake increases the chance of introduction by watercraft and residential activities. Once established in a waterbody, they can expand aggressively because of their growth characteristics and lack of predators. Eurasian water-milfoil can spread easily because new plants can grow from small fragments of stems, and it can crowd out other plants because it grows in thick, dense mats. Curly-leaf pondweed grows in dense stands and forms an abundance of turions that produce new plants during the next growing season.

Purple loosestrife and giant reed have had similar effects on plant communities of swamps and marshes. Disturbances to natural vegetation from farming, building, and practices that directly remove native vegetation increase the spread of invasive plants.

Zebra mussels and non-indigenous zooplankton have caused shifts in the species composition and abundance of lower food chain biota. This has been ongoing in the Great Lakes and is beginning in inland lakes as these species expand their range. Gobies and ruffe are new species to the Great Lakes that are highly competitive and are expected to cause shifts in biological communities. Invasion by rusty crayfish has resulted in the extirpation of native crayfish in some Michigan systems.

Shoreline Development

Construction of buildings, seawalls and lawns along lakeshores removes natural vegetation that mammals, birds, amphibians, reptiles, and fish require. Septic tanks and lawn fertilizers leach nutrients into the lake, having the same effects on water quality as agricultural fertilizers. Wetlands are often cleared and drained for buildings. Many Michigan lakes presently have little, if any, naturally sloped or vegetated, shoreline remaining.

Dredging and Filling

Dredging and filling activities occur for many reasons and alter the natural habitats and communities in a lake. Generally, most dredging activities are conducted in the littoral zone, altering the most biologically productive area of lakes. Filling activities may be conducted in any part of the lake, often including the shoreline ecotone. Filling within the shoreline ecotone is responsible for the loss of many wetlands. Filling within the lake removes valuable, productive aquatic habitat and removes navigable waters from public use. Dredging and filling is typically conducted for marina and dock construction, boating channels, dockage, seawall construction, extension of upland properties, removal of sediment and vegetation, building construction, beach sanding, waste disposal, and reef construction.

Seawalls are constructed along the shore of lakes to prevent natural erosion of the shoreline. Seawalls eradicate the natural slope of the shoreline caused by wave action and annual water level changes in lakes. They also are constructed to provide docking of boats and to provide a manicured look to lawns and properties along the shoreline. Seawalls are constructed of metal, stone, or wood, and may extend out into the lake or inland above the ordinary high water mark. The construction of seawalls has increased significantly in recent years and many of our lakes have almost no naturally shaped shoreline areas remaining.

Seawalls are detrimental to lakes in many ways. They generally remove the natural slope of the shoreline and create barriers that prevent the free migration of mammals, reptiles, and amphibians between the water and uplands. They remove the natural energy dissipating capacity of a sloped shoreline and natural vegetation, and this, in turn, causes increased erosive energy in other parts of the lake along with additional scour and deepening of the bottom and further removal of natural vegetation.

Dike and channel construction have caused significant alteration of Great Lakes marshes, especially in the southern half of the Lower Peninsula (Albert et al. 1988). Creating dikes in coastal wetlands has been done to allow farming of the productive soils and for waterfowl management. The use of dikes and pumps has helped remove water to allow farming, or to stabilize water levels in marsh communities. However, dikes are barriers that prevent natural interchange of water between deep portions of the lake and littoral areas. This interchange includes daily (wind seiche), seasonal, and long-term water-level changes that result in exchange of water, nutrients, and energy. The disruption of regular de-watering or movement of oxygenated lake water into coastal wetlands must be critically evaluated, and some dikes have been removed from state-owned coastland (Soulliere 1995). Dikes fragment coastal wetlands, reduce vegetative diversity (Keddy and Reznichek 1984), reduce water quality and fish use, and simplify invertebrate communities (Edsall 1988). Commercial dredging to create, deepen or widen channels will directly take vegetation, remove soils necessary for plant establishment, and increase rate of water flow, making it more difficult for plants to re-establish. Additional habitat degradation may occur when dredge spoils are deposited in other parts of a lake.

Reef construction is often proposed to improve fishing and diving recreation, both on the Great Lakes and inland lakes. Proposals often incorporate the use wood and foreign materials including: stone, tires, slag and other industrial waste, automobiles, buses, and ships. The use of artificial reefs to enhance habitat and improve biological communities in oceans, lakes, and reservoirs has questionable value (Merna and Galbraith 1984; Ganon 1990; Tugend et al. 2002). The principal result that artificial reefs sometimes provide to anglers is the attraction of fish to locations where they are more susceptible to angling. This often leads to management conflicts when harvest is being reduced in other ways. Great Lakes management agencies developed the International Position Statement and Evaluation Guidelines for Artificial Reefs in the Great Lakes (Ganon 1990). This document states "artificial reefs should be constructed only when there are clear benefits to fisheries without deleterious effects on the ecosystem or undue interference with other beneficial uses of the lakes", and "under no circumstances should artificial reef development be used as a pretext for the disposal of terrestrial refuse into the aquatic environment." The addition of natural materials to lakes may be acceptable when completed in an ecologically sound manner, for example, littoral zone deadwood restoration discussed in this document.

Aquatic Vegetation Control

Aquatic vegetation is removed from lakes to control non-indigenous species, to clear the surface of the lake for boating, to clear areas for swimming near shore, and to create "clean," open-water appearances to lakes. The removal of native aquatic vegetation is detrimental to lakes because vegetation forms the base of the food chain and is a principal habitat component for aquatic life. Removing native vegetation destroys microhabitats, shortens food chains, opens the lake bed to invasion by non-indigenous species, and opens the shoreline to wave erosion. Removal of native vegetation promotes the spread of aggressive, non-indigenous species.

There is sometimes a social misconception in Michigan that aquatic macrophytes are bad for a lake. This negative misconception is fostered by boating and swimming enthusiasts that consider vegetation a "nuisance" to these recreational activities. The expansion of non-indigenous aquatic plant species and their control also fuels this misunderstanding. The effects of nutrient pollution are also often misunderstood and used to promote plant removal programs in lakes.

Nutrient pollution affects aquatic plant communities. Generally, excessive nutrient pollution typical of eutrophic lakes results in algal populations that can be significantly higher than normal. Increased algal biomass reduces underwater irradiance that inhibits macrophyte growth, resulting in diminished macrophyte communities. High algal populations occur when high concentrations of dissolved nutrients are present in a lake. Rooted aquatic macrophytes derive most of their nutrients from the sediments. Generally, in oligotrophic and mesotrophic lakes, nutrient enrichment of the sediments increases macrophyte biomass. Duarte and Kalff (1988) found that macrophyte biomass averaged 2.1 times greater when nutrients were added. Eurasian water-milfoil has been shown to increase biomass by 30–40% with nutrient enrichment of the sediments (Anderson and Kalff 1986). As discussed earlier, canopy-erect macrophyte species dominate areas of a lake with high sediment nutrients, while bottom-dwelling species dominate infertile sediments. Usually, the greatest plant biomass increases are likely to occur in the shallow parts of the littoral zone, where nutrients tend to be more limited.

Plant control programs designed to kill native plants do not address the nutrient pollution issue because the nutrients are cycled back into the system. This also can foster greater growth of the two important non-indigenous species, curly-leaf pondweed and Eurasian water-milfoil, because they are both canopy-erect species favoring nutrient rich sediments. The killing of bottom dwelling species that favor nutrient poor sediments also promotes the expansion of canopy-erect species because it speeds the process of sediment nutrient enrichment. Other related issues are discussed below.

There are numerous methods used to remove or control aquatic plants. All methods have advantages and disadvantages. Appropriate non-indigenous plant control methods will vary depending on individual lake conditions such as size, depth, chemistry, and the distribution and abundance of plant species. Generally, integrated control using multiple methods will be necessary for long term management.

Mechanical methods of aquatic plant removal include bottom barriers, suction or diver's dredge, hand removal, rotovation (bottom tilling), dredging or filling sediments, and harvesting by cutting the upper portion of plants. Bottom barriers, dredging, filling, and rotovation are non-selective methods that remove both non-indigenous and native plants. Hand removal (cutting, pulling, or raking) and mechanical harvesting can be very selective and can be used to only remove a portion of the plant. The more selective methods can be used to maintain open boat channels through native plant stands, from docks to open water, without leaving the bottom open to invasion by non-indigenous species**.** Mechanical harvesting causes fragmentation of plants, and should be avoided in lakes that have low to moderate levels of Eurasian water-milfoil. Eurasian water-milfoil plants can grow from small fragments, so methods that fragment plants magnify the potential this plant will increase its distribution in a lake. Mechanical harvesting removes plants and associated nutrients from lakes, but also removes many juvenile fish.

Biological methods of plant removal or control presently include introduction of herbivorous fish or insects, and the use of plant pathogens or growth regulators, which are relatively new procedures under study. Introduction of herbivorous fish, like the grass carp or white amur, is not allowed in Michigan because of the potential for damage to native vegetation. The aquatic weevil *Euhrychiopsis lecontie* is very selective and has been effective in controlling Eurasian water-milfoil (Sheldon and Creed 1995). Herbicide use and mechanical harvesting can reduce populations of herbivorous weevils (Chambers et al. 1994; Sheldon and O'Bryan 1996), and should be avoided when weevils are present.

Chemical control of aquatic plants is presently the most widely used method in Michigan. Herbicides for aquatic plant control can be described by the following general categories:

- Contact herbicides are plant control agents that are used in direct contact with foliage and destroy only the contacted portion of the plant.
- Systemic herbicides are applied to foliage and are translocated to roots or other portions of the plant, resulting in death of the plant.
- Broad-spectrum herbicides kill most if not all plants.
- Selective herbicides only kill certain plants or plant families.
- Broadleaf herbicides generally kill dicotyledons (dicots) with broad leaves.

Contact and broad spectrum herbicides generally remove native as well as exotic species. Recent studies indicate some contact herbicides can be used selectively for non-indigenous plant control early in the growing season, before native plants have emerged.

Systemic, selective, and broadleaf herbicides are generally more selective but usually kill some native plants along with non-indigenous species. Most often, the sensitivity of all plants in a lake to herbicides is not known. A good example is 2,4-D, a widely used broadleaf, systemic herbicide primarily used for control of Eurasian water-milfoil. At concentrations normally applied in lakes, 2,4-D kills broadleaf dicotyledons and monocotyledons with broadleaf morphology, but does not harm certain narrow-leaf dicotyledons (Washington State Department of Ecology 2001). In Michigan, there are 141 species of submersed and floating-leaf plants. Of these, 57 (40%) are dicotyledons, with 2 non-indigenous species and 14 threatened, endangered, or special concern species (Appendix 1). Lower concentrations of 2,4-D are more effective because high concentrations tend to “burn” the plant rather than kill it. Although 2,4-D is generally used to control Eurasian water-milfoil, at normal concentrations it also kills native milfoils and water star-grass, and at higher concentrations bladderwort, fragrant water-lily, yellow water-lily, watershield, and coontail. It also causes declines in other native species that generally recover by the end of the growing season. It is known that 2,4-D has some toxic effects on benthic organisms; information on amphibians, reptiles, and insects is lacking.

Recent studies indicate wild-rice also is affected by 2,4-D, as well as by Diquat (REWARD), endothall (Aquatholl), and fluridone (Nelson et al. 2003). Wild rice was affected to the greatest extent by 2,4-D, with significant inhibition of tiller, seedhead, and dry weight biomass production. The other chemicals inhibited dry weight biomass of young wild rice. None of these chemicals affected mature wild-rice plants. Many applications of herbicides in Michigan are applied during the early growing season when wild-rice is in the early stages of development.

Fluridone is another systemic herbicide used to control Eurasian water-milfoil. Fluridone is generally used for control programs targeted at entire lakes because it dissipates in water and cannot be controlled in small areas. Studies in Michigan found that fluridone will kill nearly all plants in a lake when used at label recommended rates (Anonymous 1997). Even at the lowest concentrations effective for controlling Eurasian water-milfoil, other common native plants are equally susceptible to fluridone (e.g., native milfoils, coontail, naiads, and *Elodea*). Other herbicides have varying advantages and disadvantages that need to be considered prior to use in controlling non-indigenous plants.

Aquatic herbicides usually do not directly kill fish at typical application concentrations, although some are more toxic than others. More often, zooplankton and macroinvertebrates are killed (Engle 1990; Washington State Department of Ecology 2001). Water quality often is affected by the use of herbicides in lakes. Dying vegetation releases nutrients and organic matter into the water that promote algal blooms. Additional applications of chemicals, primarily copper products, are then employed to control filamentous and planktonic algal blooms. Dying vegetation can also result in low dissolved oxygen concentrations in the water that may result in fish mortalities under certain conditions. Algal blooms and low dissolved oxygen concentrations both can become more pronounced as larger areas and amounts of vegetation are killed.

Copper compounds are used for algae control. Copper is the active ingredient in these products. Copper does not degrade and remains in the sediments of a lake indefinitely. The State of Washington has banned the use of copper in salmonid waters due to toxic effects (Washington State Department of Ecology 2001). The State of Washington also greatly restricts the use of copper compounds in other water bodies due to toxic effects on plants and invertebrates. Recent studies in Michigan indicate the use of copper products for control of algae and swimmer’s itch (see below) can result in significant increases in copper concentrations in the sediments, with measured increases as high as 10 times natural levels (Harrison 2003).

Lake managers sometimes assume that removal of abundant plants will result in significant improvement in the size structure of slow growing bluegill populations. However, there is little empirical evidence that bluegill population size structure will improve substantially, especially for extended periods. The lack of long-term studies relating vegetation manipulation and fish populations is discussed by Carpenter et al. (1995). Schneider (2000) found some improvement in bluegill populations with removal of vegetation. Some lakes showed bluegill populations moving from poor to satisfactory levels, while others remained unsatisfactory. Olson et al. (1998) showed short-term improvement in fish growth following a specific type of mechanical harvesting pattern of vegetation.

Macrophyte densities were very high and changes lasted for 1 season because vegetation grew back rapidly. In general, modeling and field studies have found that reduction of abundant, dense plant communities can increase growth and size structure of some fish, for a short time. Other methods are available for improving the size structure bluegill populations for fishing (Schneider 1993; Schneider and Lockwood 1997). Management programs designed for manipulation of specific components of a biological community must consider overall health of the ecosystem, including community rather than individual species evaluations.

Modifying a bog to convert it to a commercial cranberry marsh will destroy the original plant community. Harvesting top layers of sphagnum for commercial market will also damage the system. Researchers have little information about the recovery rate of harvested bogs but assume recovery is probably very slow or may never occur depending on the site and other land use that may be influencing the site. For example, increased nutrient supply from adjacent agricultural land may cause the edge of the bog mat to decompose at a faster than normal rate, increasing the size of the moat and potentially destroying the bog.

Swimmer's Itch Control

Swimmers itch (cercarial dermatitis) is caused by a larval stage of a flatworm that inadvertently burrows into the human skin. The flatworm cannot develop into the adult form, but can cause skin inflammation to allergic individuals. Control of swimmer's itch is directed at certain species of snails that serve as intermediate hosts for the flatworm. Very high concentrations of copper (>20 mg/l) are required to kill snails in waters of a lake. The high copper concentrations can kill confined fish and also other aquatic life susceptible to copper toxicity.

Blankespoor and Reimink (1991) summarized the history of swimmer's itch control in Michigan. Control programs began in the late 1930s, and have focused on the use of copper compounds. Swimmer's itch continues to be a problem in Michigan despite more than a half century of control efforts. Balankespoor et al. (2001) found that treating water birds with the drug praziquantel was effective in reducing levels of swimmer's itch, and they have used this method successfully in a number of Michigan lakes.

Species of birds that have been found to carry the flatworm include common merganser, wood duck, mallard, Canada goose, and grackle (Blankespoor and Reimink 1991). The common merganser generally is the most common flatworm carrier with high infection rates. Directing treatment programs at water birds may be more effective because typically not more than 50 will be present on a lake compared to many thousands of snails, and birds have very high infection rates compared to snails. Blankespoor and Reimink (1991) report that drug treatments of water birds appears to be more effective in controlling swimmer's itch than using copper sulfate to kill mollusks, and at the same time reduces costs and environmental risks.

Boating and Shipping

Boating is most detrimental to lakes when large areas of vegetation are removed to promote this activity. Vegetation control programs often target removing all vegetation within a lake that grows near the surface or in areas that inhibit the use of motors and water skiing. Substantial amounts of native vegetation removed for this purpose affect the overall ecology of the lake. The wave energy associated with high-speed boating causes beach erosion, which is exacerbated by removal of surface-growing vegetation that naturally provides wave energy reduction. Boating through vegetation also causes a great deal of fragmentation of vegetation that can promote the spread of invasive plant species. Shipping can be destructive to lakes by causing shoreline scour and vegetation removal resulting from water and ice surges as large ships pass.