# Distribution and ecological characteristics of fish species-at-risk in the Great Lakes basin

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## Abstract

Many fish species are considered to be at risk in the Great Lakes basin. The likely cause for their declines are, in many cases, either assumed or unknown. Numerous factors within the environment of these fishes are likely to have a direct effect on the species themselves, but the question remains: what species and why? Do certain species have ecological characteristics that may make them more susceptible to decline? In the past, political jurisdictions within the United States and Canada have enacted conservation programs separately. The current study is the first basin-wide fish species-at-risk analysis. A comprehensive species-at-risk list was created for the Great Lakes basin by referring to state and provincial at-risk lists as well as other non-governmental conservation agencies. Distribution maps for species at-risk in the basin were developed using a geographic information system (GIS) by compiling existing digital data and also by converting distribution data from non-digital formats. An analysis was undertaken to determine if ecological and life-history traits varied significantly between fish species at-risk and not-at-risk in the Great Lakes basin. Data for traits were gathered from published and unpublished sources. Using statistical analyses (i.e. Mann-Whitney, Kruskal-Wallis, logistic/multiple regression, discriminant function analysis), it was determined that fish species-at-risk in the Great Lakes basin are more likely than species not-at-risk to exhibit *K*-selected life-history traits or to be specialized for particular feeding and/or breeding behaviors.

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# 1.0. Introduction

Increased disturbances in aquatic ecosystems have brought about a need for effective conservation efforts to combat the impact of habitat and community alterations (Lande, 1988). It is important that the integrity of species habitats be maintained for the preservation of species. Yet, it is vital that efforts to preserve one species not negatively affect others (Winemiller and Rose, 1992). Ecosystem-based management is perhaps the most reliable means for ensuring successful preservation of entire aquatic systems. Although accounting for all natural factors in an ecosystem is difficult, the community as a whole has a much greater chance of being preserved because the biological community is inter-related as a single entity (Wilson, 1997).

Fish species within the Great Lakes basin have been subjected to many forms of disturbances. Habitat alterations, overexploitation, pollution, and introduction of exotic species have adversely affected fishes. The result is that there are an alarmingly high number of fishes that are now believed to be at-risk of extirpation in the Great Lakes basin. Conservation efforts by political and wildlife agencies within the Great Lakes basin have been effective, however, the concept of preserving ecosystems rather than single species, has caused current conservation policies to be called into question. To preserve the fishes of the basin, the various governments and agencies now need to work as a single unit, taking advantage of the extensive yet fragmented knowledge base of Great Lakes fish species-at-risk.

The objective of the current study is to complete the first basin-wide analysis of Great Lakes fish species-at-risk (SAR). Fish SAR lists were compiled from the nine political jurisdictions within the basin, as well as six additional conservation agencies.

This information was used to create a comprehensive list of at-risk fishes for the Great Lakes basin. The rankings of species at-risk in the basin have been fragmented between the political jurisdictions in the Great Lakes region. Those data were gathered and compiled into distribution maps for each fish species-at-risk in the Great Lakes basin. Past studies have attempted to determine if the ecology and life-histories of fishes at-risk and not-at-risk differ significantly using statistical models (e.g. Parent and Schriml, 1995, Duncan and Lockwood, 2001). These studies proved successful, but these methods have never been applied to all fishes of the Great Lakes basin. Ecological and life-history data were gathered for both species at-risk and not-at-risk from primary and secondary literary sources. Univariate and multivariate statistical tests were then used to determine if there were significant differences in the ecological and life-history characteristics of fish species at-risk and not-at-risk in the Great Lakes basin.

### *1.1. History*

The Great Lakes ecosystem has been exploited by humans for over 5,000 years (Bogue, 2000). As early as 3,000 years before present, Native American fisherman were using large-catch fishing methods such as gill nets, hooks-and-lines, and weirs to improve their catches. These catch efforts were vital to the survival of the local tribes, but their total catch weights were not large enough to have significant negative impacts on native game fish populations. Through this relationship, human and fish populations coexisted in general security for several thousand years. It was not until the arrival of European settlers in the late eighteenth century that native fish populations began to suffer from the increasing presence of humans in the Great Lakes basin. The abundance of large and flavorful game fishes, salmonids in particular, was an invitation for local fishermen to catch or harvest as many fish as possible. The pioneer fisherman began to employ capture methods learned from the native peoples. Fishermen utilized the knowledge of fishes' spawning seasons and spawning locations to their advantage and were able to trap fishes by the hundreds while they attempted to spawn. Local game fish populations began to decrease rapidly. If one fish species became too hard to catch, they simply switched their aim toward other fishes (Bogue, 2000).

Soon, local subsistence fishers would become only a small part of the problem with the rise of commercial fishing, which came to prevalence in the early nineteenth century. Commercial fisherman continued the established methods of targeting fishes on their spawning grounds. However, the increased ability of fishing boats to store larger hauls led to the rapid demise of preferred fish species. An early example of the commercial fisheries' overzealous practices was the Atlantic salmon, *Salmo salar*. It was once said early in the nineteenth century that Atlantic salmon were so abundant that "...men slew them with clubs and pitchforks – women seined them with flannel petticoats....Later they were taken by nets and spears, over one thousand being often caught in the course of one night," (Bogue, 2000). Trap nets were first developed for use in 1850 along the southern shore of Lake Ontario. These new devices were placed directly in the mouths of Atlantic salmon spawning streams to catch entire populations of the fish as they attempted to move upstream to breed. The introduction of trap nets virtually destroyed the Atlantic salmon populations on the southern shore of Lake Ontario in less than five years. With the depletion of key stocks like the Atlantic salmon, similar fates would befall the whitefishes, sturgeons, trouts, and herrings (Bogue, 2000).

State governments within the Great Lakes basin realized a need to preserve these important fish stocks in the early days of established commercial fisheries. The state government of New York was the first to take such action. In April, 1801, a measure was approved which prohibited the use of seines, nets, weirs, and other obstructive measures on certain rivers and creeks, or within 1,650 feet of the mouths of those certain streams, to divert salmon from ascending to their spawning grounds. The Canadian government passed similar Great Lakes legislation in March of 1807. The New York law, despite its overtones of species conservation, was actually passed to keep the salmon stocks at a level that would allow the fishery to be maintained. The salmon fishery was far too lucrative to eliminate. The Canadian legislation, on the other hand, was actually intended for the preservation of species, regardless of financial losses to the fishery. Despite these initial attempts to protect these fishes, the laws were generally ignored by local enforcement agencies. The laws provided for no threatening punishment for violators, and enforcers were not compensated for capture of violators. Enforcing the laws proved to be a bother and the laws were all but forgotten (Bogue, 2000).

American states continued to pass piecemeal legislation for fish species protection, which were, as before, generally focused on preservation of commercially valuable stocks. Canadian legislation continued to build upon the 1807 law, and passed many separate laws and regulations. In 1857, the legislative bodies within Canada began to create a single fisheries protection act that was formed from the best aspects of the previous fifty years of legislation. This effort culminated in the *Fishery Act* of 1868. This act provided new ideas about how to preserve fish species that are still practiced today. Regulations included closed seasons during spawning, restrictions on where fishing was allowed, fishways for dams, severe penalties for fishes taken out of season, and protection of fishes in sensitive areas. This act also prohibited dumping of organic and inorganic wastes and chemicals (Bogue, 2000).

The United States did not pass such sweeping legislation of its own in reaction to Canada's *Fishery Act* of 1868. American states were basically left to regulate the Great Lakes on their own. Yet, the Canadian government consistently urged the United States federal government that a joint effort was necessary to provide true preservation of Great Lakes species. Although the United States avoided such joint ventures for years, the government eventually realized the need for international legislation. This cooperative effort resulted in the Canadian-American Joint Commission of 1892. The mission statement for the commission was to "promote the propagation and protection of fish in the common inland water". This was the first time that both federal governments agreed to consider the Great Lakes basin as a single hydrologic unit (Bogue, 2000).

Despite these efforts, the damage had already been done by nearly a century of unchecked and virtually unregulated commercial harvesting of large fishes. Prior to the year 1800, fish communities were dominated by large individuals of large species, such as lake sturgeon (*Acipenser fulvescens*), channel catfish (*Ictalurus punctatus*), northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), lake whitefish (*Coregonus clupeaformis*), lake trout (*Salvelinus namaycush*), Atlantic salmon (*Salmo salar*), and walleye (*Stizostedion vitreum*). It was estimated that at least half of the total biomass of fishes in the Great Lakes was made up by individuals greater than five kilograms in mass (Francis et al., 1979). Before European settlement, the Great Lakes was a collection of pristine aquatic environments. There was low accumulation of organic silts and sediments except for areas where the current allowed such buildup, such as marshes and bays. The waters rarely reached anoxic conditions except in lagoons where water could become stagnant. The stream flows during summer months were abundant, cool, and clear. Wetlands and macrophyte beds were extensive. Waters of the lakes themselves were generally cooler and clearer, being of low productivity. And perhaps most important to fishes, there were no exotic species (Francis et al., 1979).

The increasing presence of humans in large numbers along the Great Lakes and within the basin would not allow those pristine conditions to last. Human encroachment led to the rapid, and in some cases very rapid, decline in native Great Lakes fishes. The stresses placed on native species by commercial fishing were one of the greatest forces acting against them (Francis et al., 1979). Threats to Great Lakes basin fishes can be grouped into four categories: (1) habitat alteration; (2) overexploitation; (3) introduced species; and, (4) pollution.

Habitat alterations to aquatic systems occurred by activities such as damming, channelization, dyking, draining, and substrate removal (Francis et al., 1979). These alterations often destroyed critical habitats for spawning and feeding. Resources were removed from river, stream, and lake beds. In many cases, the resources being removed were essential to some aspect of the fishes' life-cycles. Habitats were also significantly altered by filling-in of wetlands and marshes. Some species, such as the spotted gar (*Lepisosteus oculatus*), spend the majority of their lives in marsh habitats (Etnier and Starnes, 1993) and the elimination of their key habitat led to their extirpation in some areas such as the south shore of Lake Erie in the Maumee River drainage (Francis et al., 1979). Dyking and flooding areas, as well as draining ponds and pools, was also common practice for creating new lands for commercial development (Francis et al., 1979).

Overexploitation of Great Lakes fishes was accomplished primarily by commercial fisheries. Commercially valuable species, such as Atlantic salmon (*Salmo salar*) and lake whitefish (*Coregonus clupeaformis*), were relentlessly harvested for the better part of a century (c.a. 1800-1900). Their populations reached a critical point at which limitations on harvesting were the only means to prevent their extirpation (Bogue, 2000). The blue pike (*Stizostedion vitreum glaucum*) suffered the worst fate due to commercial fishing pressure. Because of its high commercial value, it was intensively harvested. This over-harvesting was the direct cause of its extirpation from the Great Lakes. The blue pike only existed in the lakes Erie and Ontario, and was globally extinct by the mid-1960's (Francis et al., 1979). Some species with no commercial value have great recreational value and have been severely impacted by intensive angling pressure. Muskellunge (*Esox masquinongy*) are prized for their aggressiveness and ability to put up a great fight when hooked on a line, (Jenkins and Burkhead, 1994) as well as the possible sizes they may attain in the Great Lakes (Becker, 1983). This led to muskellunge being heavily targeted by anglers, and if landed, a trophy muskellunge was rarely released (Jenkins and Burkhead, 1994).

Introduction of exotic species has had extensive negative impacts on both Great Lakes basin fishes and the habitat itself. Common carp (*Cyprinus carpio*), introduced from Europe, are capable of destroying large macrophtye beds by uprooting plants in search of food (Trautman, 1981). Although there is little evidence that carp are heavily competing with other fishes for some ecological niche, their ability to destroy habitat makes them a considerable threat to native fishes. However, threats not only come from introduced fishes, such as sea lamprey (*Petromyzon marinus*), round goby (*Neogobius melanostomus*), and alewife (*Alosa pseudoharengus*), but from other introduced taxa such as the zebra mussel (*Dreissena polymorpha*), which has significantly impacted lower levels of the Great Lakes food webs. By filtering feeding, they remove phytoplankton and other microorganisms that planktivorous fishes would feed on. At first, it appeared the zebra mussels would help lower the turbidity of the waters, which did happen. Yet as their populations grew continually larger, they drastically limited the populations of microorganisms at the base of the pelagic food web (Idrisi et al., 2001). This appeared to be detrimental to planktivorous fishes, such as minnows (Cyprinidae) (Kilgour et al., 2000). However, recent studies have shown that the presence of zebra mussels in the Great Lakes has not significantly altered benthic communities or food webs (Kilgour et al., 2000). The round goby originally is believed to be a significant threat to native fishes, such as the mottled sculpin (*Cottus bairdi*), through competition for resources (Janssen and Jude, 2001). New evidence suggests, though, that the round goby is beneficial because they are utilizing the zebra mussels as a food source, and their predation significantly decreases zebra mussel populations (Djuricich and Janssen, 2001). Despite their newfound benefits, the round goby's negative affect on native species continues to be a problem (Janssen and Jude, 2001).

Introduction of exotic species by both intentional and accidental release was perhaps one of the greatest challenges to the native fish species. Since the rise of commercial fishing in the Great Lakes in the early nineteenth century, exotic game species were introduced to replace the crashing native game fish fisheries. A favorite group of fishes to introduce into the Great Lakes were salmonines native to western North America known generically as Pacific salmon (i.e. pink salmon (*Oncorhynchus gorbuscha)*, coho salmon (*Oncorhynchus kisutch*), rainbow trout or steelhead (*Oncorhynchus mykiss*), and chinook salmon (*Oncorhynchus tshawytscha*)). A few of these introduced species have been able to establish populations in the Great Lakes (Francis et al., 1979). Those unable to establish themselves are maintained by stocking from state and provincial governments. Continued stocking of non-native species allows the populations of introduced fishes to remain large enough to strongly compete with, and in some cases outcompete, native species. Introduction of alewife (*Alosa pseudoharengus*) and rainbow smelt (*Osmerus mordax*) have contributed to losses of native species as well. Alewives were able to proliferate due to the reduction of large piscivores, largely due to sea lampreys, and have altered pelagic food webs by lowering the number of large zooplankton. This has caused a gap at the base of the food chain and disrupted the food webs of the ecosystems. Large alewife die-offs have also endangered water supplies for human use and habitats for fishes (Francis et al., 1979).

The sea lamprey (*Petromyzon marinus*), a fish that parasitizes fishes, has become a problem in the Great Lakes basin. Originally a marine species, it was introduced into Lake Ontario but was confined there by Niagara Falls. The building of the Welland Canal provided them an open pathway to the Upper Lakes (Daniels, 2001). The sea lamprey has caused drastic declines in many fish species, although it apparently prefers the thin cycloid scales of salmonines. The impact of the sea lamprey's presence became apparent with the extirpation of the lake trout (*Salvelinus namaycush*) from Lake Michigan by 1956, and the crash of lake trout populations in Lake Huron and Lake

Superior. Efforts to restock the Upper Lakes with hatchery-raised lake trout have been only mildly successful now due to early mortality syndrome (EMS) that severely limits lake trout recruitment (Honeyfield and Hinterkopf, 2002). Alewives contain strains of bacteria which produce a substance known as thiaminase that can degenerate the protein thiamin. Thiamin is a key substance produced by fishes' bodies for healthy development of gonad. As lake trout consume alewives, they begin to bioaccumulate thiaminase, which weakens their reproductive capability. The loss of fitness in the adults results in loss of fitness in the offspring, thereby increasing mortality of the offspring (Honeyfield and Hinterkopf, 2002). Although not as prevalent as they once were, sea lamprey scars are still being found on the majority of large fish species in the lakes, including the thick-scaled suckers (Catostomidae). Attempts to control the sea lamprey have been successful and the populations show trends of decline (Johnson et al., 1999). Barriers and fish traps have been constructed in sea lamprey spawning streams to prevent them from reaching preferred spawning grounds. Unfortunately, these barriers may prevent native species from reaching preferred spawning habitat as well. The use of an ammocoete-specific toxicant called 3-trifluormethyl-4-nitrophenol (TFM) in spawning streams to kill off juvenile sea lampreys during the few years they spend living in the stream substrate has been successful. The use of TFM in Lake Superior tributaries reduced sea lamprey numbers enough to allow hatchery-raised lake trout to establish a non-breeding population. Similar results have occurred in Lake Huron and Lake Michigan through the use of TFM (Francis et al., 1979). It has been suggested that the use of TFM has had little to no effect on non-target fishes (Johnson et al., 1999). However, studies have shown that non-target native lampreys, such as the northern brook lamprey

(*Ichthyomyzon fossor*), are strongly affected by TFM when used in higher concentrations (King and Gabel, 1986). There are also concerns that TFM may be a carcinogen to humans and other terrestrial animals.

The effects of pollution on fishes in the Great Lakes basin has been extensive. Nutrient loading has led to eutrophication of waters. This eutrophication caused massive algal blooms throughout the Great Lakes. In the late 1950's and 1960's, Lake Erie experienced intense algal blooms resulting from increased phosphorous inputs (Ludsin et al., 2001). When the algae died, they sank to the bottom of the lakes and their decomposition led to anoxia in the benthos (Francis et al., 1979). Benthic fishes, like the burbot (*Lota lota*) (Becker, 1983), have difficulty surviving in such conditions (Waters, 1995). As a result, their populations decreased readily (Francis et al., 1979). Other forms of pollution resulted in increased turbidity in tributary streams and rivers. Agriculture, forestry, mining, urban development, and streambank erosion all significantly affected the aquatic communities. The destruction of wetlands, marshes, and riparian cover eliminated sedimentation buffers, which increased the turbidity of the tributaries and near shore lake waters (Waters, 1995). Species such as the silver shiner (*Notropis photogenis*) and the channel darter (*Percina copelandi*) with low tolerance for turbidity (Portt et al., 1999) were forced out of preferred habitats (Waters, 1995).

### *1.2. Species at Risk*

Freshwater fishes are the most diverse vertebrate group, and are also the most highly at-risk vertebrate group (Duncan and Lockwood, 2001). This trend applies to the Great Lakes basin as well. Conservation efforts of the past had positive intentions, yet were ultimately not as effective as they should have been. This may be due in part to conservation efforts being improperly based and targeting species for the wrong reasons. As the Canadian government pushed for a joint U.S.-Canadian effort in the mid-nineteenth century, a need has once again surfaced for a basin-wide approach to fish species conservation.

An example of where such an approach is necessary is in the (SAR) lists developed by jurisdictions within the Great Lakes basin. The SAR lists differ greatly from one state to another, from one nation to the other. In many cases, a species may be listed as being endangered in one jurisdiction, while it is considered not at risk in the neighboring jurisdiction, even if it is in the same watershed. These significant differences may render the conservation efforts of one jurisdiction virtually ineffective. A single fish species-at-risk list for the entire Great Lakes basin would aid in unifying the conservation efforts put forth for all at-risk species. Therefore, a comprehensive listing of fish species-at-risk in the Great Lakes basin is needed.

Distributions of fish species-at-risk for the Great Lakes basin must be made current. Fish SAR distribution maps have never been produced for the basin as a whole. With the development of digital mapping software, maps can be created and easily edited to reflect changes in species' distributions. The need for updated maps, however, goes beyond simply keeping up with technology. The maps can be manipulated to display the distribution of all SAR fishes, as well as the distributions of each species. By creating a map that displays all species at risk distributions, areas within the basin at which there is a high concentration of at-risk species can be identified for rehabilitation and monitoring efforts to reduce negative impacts on fish populations. Individual maps can identify target areas for conservation efforts intended for particular species, as well as show trends in a species' decline or provide data for re-evaluation of conservation statuses.

Of the 192 fish species in the Great Lakes basin (Coon, 1999), 166 are considered native species. Eighty of those native species are listed as at-risk by at least one jurisdiction. Why are some species at-risk while others are not at-risk? It has been suggested that each species may have a specific trait that causes it to be more susceptible than other species (Parent and Schriml, 1995). However, conservationists need to be able to identify a set of ecological and biological traits that make species more likely to decline than other species (Duncan and Lockwood, 2001). Understanding why species are at-risk can only be achieved by comparing them to species that are not at-risk. Are aspects of their life-history traits and ecological characteristics significantly different? Or, is the overexploitation of these fishes the main reason for their decline?

The analyses of ecological and life-history characteristics were modeled after previous studies. Parent and Schriml (1995) utilized univariate statistics to determine that seven out of 51 ecological traits and life-history characteristics (use of grass as feeding substrate, use of gravel or pebble as breeding substrate, lake as feeding habitat, streams as breeding habitat, piscivorous feeding, age at maturation, speed of current over feeding area) differed significantly between species at-risk and not at-risk in the Canadian Great Lakes-St. Lawrence biozone. The accepted logistic regression model correctly classified 97.1% of the 117 species included in the analysis (Parent and Schriml, 1995).

Morris (2002) completed a similar analysis as Parent and Schriml (1995) for two subsets of fish species: (1) all Canadian freshwater fishes; and, (2) fishes that occur in the Canadian portion of the Great Lakes basin. Along with a logistic regression model, Morris (2002) included stepwise and standard discriminant function analyses that would re-classify species based on the variables entered in the discriminant function. He found that nine ecological and life-history variables were significant between the fishes with and without a COSEWIC status. For the Great Lakes species data set, which consisted of 124 species, the stepwise logistic regression model had an 89.0% correct classification rate at a decision level of 30%. The stepwise discriminant function correctly classified 76% unranked and 80% of ranked species. The three discriminant functions correctly classified 57% of unranked species, 60% of special concern species, 75% of threatened species, and 100% of extirpated species (Morris, 2002).

The objectives of this study were: (1) to create a single, comprehensive fish species-at-risk list for the entire Great Lakes basin; (2) to develop digital distribution maps for all species at risk in the Great Lakes basin; and, (3) to determine if ecological traits and life-history characteristics differ between fish species-at-risk and not-at-risk.

It is hypothesized that species that possess *K*-selected characteristics (long life, slow growth, delayed maturation) will be more at risk than *r*-selected species (short life, fast growth, early maturation) (Stiling, 1999). Species with *K*-selected traits usually exhibit higher fecundity than *r*-selected species because *K*-selected species will spawn larger clutches of eggs or will lay larger eggs. Each spawning attempt may be successful, but these species spawn once a season, and do not always spawn in consecutive years. Some *r*-selected species may spawn five or more times in a single season, and although each brood may have a high mortality, the chances that a sufficient cohort will survive is greatly increased (Winemiller and Rose, 1992). For *K*-selected species, any disturbance that increases mortality in their annual spawning could result in reproductive failure.

## 2.0. Methods

The species used in this study were based on Coon (1999). This list was compared to species-at-risk lists for all political jurisdictions within the Great Lakes basin (IN, IL, NY, MI, MN, OH, ON, PA, WI), as well as the at-risk lists for the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), The World Conservation Union (IUCN), and The Nature Conservancy. There are currently two formats used to rank species within the basin. The traditional ranking method (Rare (Vulnerable, Special Concern also used for this category), Threatened, Endangered, Extirpated) was employed by all eight states and Ontario within the basin, as well as COSEWIC and the IUCN. The Natural Heritage Information Center (NHIC) ranking system (S1, S2, S3, SX) (Table 1) was employed by four states (MI, NY, PA, WI) and the province of Ontario. The Nature Conservancy's Global Conservation Ranks were also summarized. A total of 16 species-at-risk lists were referenced (Table 2). The information gathered from these lists was compiled into a single species-at-risk master list for the Great Lakes basin. Fish species assigned at least one conservation status using either ranking method were placed on the list, and all rankings were included.

Distribution maps were created for all species listed on the species-at-risk master list based on data from a variety of sources (Table 3). These maps summarized the presence or absence data for each of the species in each of the 165 watersheds in the Great Lakes basin (Figure 1). Digital records of species' point distributions already compiled were imported directly into a single Microsoft Access master database. Data were also obtained from hardcopy maps for jurisdictions without existing digital databases. Distribution maps were scanned into digital images, imported into ARCView

GIS as image files and matched to a map of Great Lakes watersheds. The image files were projected to match the watershed map. Points were digitally overlaid on the scanned distribution points. The latitude and longitude coordinates for the digital points were exported into a Microsoft Excel spreadsheet, and then imported into the Access master database.

Illinois, Indiana, and Pennsylvania have geographically limited areas that fall within the Great Lakes basin. Historically, these small areas have been repeatedly sampled at the same locations. To code and add these distribution points, transparencies were made of the reference maps from each of the three selected state fish books (i.e. Blatchley, 1938, Cooper, 1983, Smith, 1979). The labeled points that fell within the Great Lakes drainage were recorded. For each Great Lakes species, the reference map transparency was overlaid to determine for which sampling locations the species had been recorded. These distribution points were input directly into the Access master database. The master database was used to produce a species-by-watershed presence-absence matrix. The presence-absence data were imported into ARCView GIS 3.2 and appended to the watershed layer. To develop each species map, the watershed layer was queried for all watersheds in which the species occurred.

The ecological database was composed of life history traits and characteristics of all native fish species in the Great Lakes basin, both at risk and not at risk (Table 4). These variables were both categorical and continuous. Categorical variables were based on a ranking system of the importance of the characteristic (1= least important, 2= important, 3= most important, 4= no preference).

Table 1. Global Conservation rankings and Natural Heritage Information Centre rankings and definitions for animal species-at-risk and their non-NHIC equivalents.

| Global Rank | State Rank | Definition | Traditional |
|---|---|---|---|
| GX | SX | Apparently extirpated; no recorded observances over extended period | EXP |
| G1 | S1 | Critically impaired; 5 or fewer occurrences, or extreme characteristic vulnerability | END |
| G2 | S2 | Imperiled due to rarity; 6 to 20 occurrences, or high characteristic vulnerability | THR |
| G3 | S3 | Rare or uncommon; 21 to 100 occurrences, or characteristic vulnerability | SC |
| G4 | S4 | Apparently secure globally/in state, but may be rare in some locations | NAR |
| G5 | S5 | Demonstrably secure globally/in state, but may be rare in some locations | NAR |

Table 2. Sources of species-at-risk lists for Great Lakes basin fishes.

| Jurisdiction | Organization |
|---|---|
| Illinois | IL Dept. of Natural Resources |
| Indiana | IN Dept. of Natural Resources |
| Michigan | MI Natural Features Inventory |
| | MI Dept. of Natural Resources |
| Minnesota | MI Dept. of Natural Resources |
| New York | NY Natural Heritage Program |
| | NY State Dept. of Environmental Conservation |
| Ontario | Natural Heritage Information Centre (NHIC) |
| | Committee on the Status of Endangered Wildlife in Canada (COSEWIC) |
| Ohio | Dept. of Natural Resources |
| Pennsylvania | Natural Diversity Inventory |
| | Dept. of Conservation and Natural Resources |
| Wisconsin | Dept. of Natural Resources (NHIC and non-NHIC ranks) |
| International | The Nature Conservancy |
| | World Conservation Union (IUCN) |

Table 3. Sources of distribution data for fishes of the Great Lakes basin.

| Jurisdiction | Source | No. of Records |
|---|---|---|
| Illinois | Smith, 1979 | 217 |
| Indiana | Blatchley, 1938 | 1,115 |
| Michigan | UMMZ, DNR | 58,785 |
| Minnesota | UMBM | 4,628 |
| New York | Smith, 1985 | 5,710 |
| Ohio | OhioEPA | 74,538 |
| | Trautman, 1981 | 909 |
| Ontario | CMN, MNR, ROM | 152,931 |
| | Stanfield, MNR | 21,485 |
| Pennsylvania | Cooper, 1983 | 319 |
| Wisconsin | Becker, 1983 | 5,149 |
| Whole basin | BILD | |

BILD – R. McLaughlin (unpublished data), CMN – Canadian Museum of Nature, DNR – Department of Natural Resources, OhioEPA – Ohio Environmental Protection Agency, MNR – Ministry of Natural Resources, Stanfield, MNR (unpublished data), ROM – Royal Ontario Museum, UMBM – University of Minnesota, Bell Museum of Natural History, UMMZ – University of Michigan, Museum of Zoology

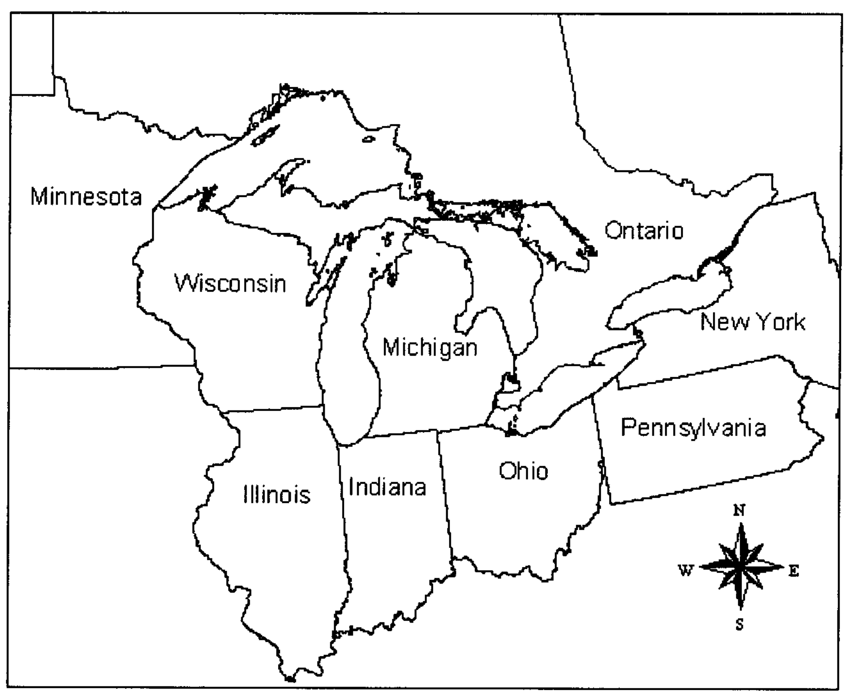


Figure 1. The Great Lakes basin.

Sixty independent ecological and life history variables were added to the database. The variables for species found in Canada were taken from Coker et al. (2001) and Portt et al. (1999). Additional data for fishes which occur only within the United States portion of the Great Lakes basin were taken from Becker (1983), Etnier and Starnes (1993), Jenkins and Burkhead (1994), Robinson and Buchanan (1988), Scott and Scott (1988), and Trautman (1981). Characteristics for each species added to the database were cross-referenced with at least two other sources before being entered into the database. This step was most important for the categorical variables (n = 56), which had to be carefully quantified to prevent incorrect interpretation of the analyses. Only four independent variables (MAXAGE, MAXLEN, REPLEN, REPAGE) were continuous. Missing data for the ecological and life history variables were coded as -9999.

Four test variables were created for the statistical analyses of the ecological database. These four variables (STATUS1, STATUS2, STATUS3, STATUS4) were based on the species at risk master list. To easier convert the listings into numerical categories, only the non-NHIC rankings were used (EXP, END, THR, SC). Some species at risk were only listed by a single jurisdiction using only the NHIC ranking system. In such cases, the NHIC ranking was converted to the analogous ranking in the non-NHIC ranking system (i.e. S1=END, S2=THR, S3=SC, SX=EXP). STATUS1 was a two-state variable that coded for a species not being at-risk (0) or at-risk (1). STATUS2 was a continuous variable that provided the total number of jurisdictions that assigned the species a conservation rank. Since only the non-NHIC scheme of classification was used for these status variables, the maximum number of jurisdictions a species could be listed by was 9 (8 states, 1 province). STATUS3 was the numerical representation of the highest conservation rank a species was given. STATUS4 was the ranking that had the highest frequency of occurrence (mode) for each species.

Basic statistics were calculated for each independent variable using Statistica Version 5.1 (StatSoft Inc., 1997) to check for the normality of the data distribution. Kolmogorov-Smirnov and Shapiro-Wilk tests for normality were used. For categorical data, the K-S $d$-scores, S-W $w$-scores, valid sample ($n$), and minimum and maximum values were recorded. For the four continuous variables, the K-S $d$-scores, S-W $w$-scores, valid $n$, mean, minimum and maximum values, and standard deviation were recorded. The four continuous variables were log-transformed ($\ln x$) and re-tested for normality using the same tests.

Correlation matrices were calculated, to identify correlated variables in the database, for the categorical and continuous variables separately using Spearman's correlation for nonparametric data. Due to limitations of the statistical software and the size of the output tables, the categorical variables were split into four subgroups. This was done by separating them into adult variables and spawning variables. The adult variables were subdivided into two groups: (1) feeding behavior; and, (2) adult habitat. Spawning variables were split into two subgroups: (1) spawning depth and flow regime; and, (2) spawning behavior and habitat. The correlation coefficients significant at $p \leq 0.05$ were identified.

Table 4. Independent variables used in the analyses of Great Lakes basin fishes.

| Variable | Description |
|---|---|
| MAXAGE | Maximum age of species |
| MAXAGEL | Log-transformed MAXAGE value |
| MAXLEN | Maximum length of a species (mm) |
| MAXLENL | Log-transformed MAXLEN value |
| LAKE | Adult/juvenile use of lake habitat |
| STREAM | Adult/juvenile use of stream habitat |
| VALUE | Human value of fish species |
| BALON_GUILD | Breeding behavior classification (Appendix A) |
| REPLEN | Body length when species becomes sexually mature (mm) |
| REPLENL | Log-transformed REPLEN value |
| REPAGE | Age when species becomes sexually mature |
| REPAGEL | Log-transformed REPAGE value |
| BO | Feed at or near bottom of waterbody |
| PE | Feed in pelagic region of waterbody |
| SU | Feed at water surface |
| NO | Non-feeding species |
| FI | Feed by filtering |
| GR | Feed by Grazing and picking |
| SO | Feed by sorting |
| ST | Feed by stalking |
| PU | Feed by pursuit |
| AM | Feed by ambush |
| PH | Feed on phytoplankton |
| MA | Feed on macrophytes |
| CR | Feed on crustaceans |
| AN | Feed on annelids |
| MO | Feed on mollusks |
| IN | Feed on insects |
| FI2 | Feed on fishes |
| PA | Feed by parasitism |
| OT | Feed by other method |
| VEGETANS | Spawning with vegetation as cover |
| ALGAES | Spawning with algae as cover |
| WOODS | Spawning with wood as cover |
| SUBSTRTS | Spawning with substrate as cover |
| OVERHEDS | Spawning with overhead cover |
| DEPTH1 | Spawning between 0-20cm |
| DEPTH2 | Spawning between 21-60cm |
| DEPTH3 | Spawning between 61-100cm |
| DEPTH4 | Spawning between 101-200cm |
| DEPTH5 | Spawning at depth greater than 200cm |
| POOLS | Spawning in pools |

Table 4 continued

| | |
|---|---|
| RIFFLES | Spawning in riffles |
| RUNS | Spawning in runs |
| RAPIDS | Spawning in rapids |
| BEDRCKS | Spawning on bedrock substrate |
| BOULDER | Spawning on boulder substrate |
| COBBLE | Spawning on cobble substrate |
| RUBBLE | Spawning on rubble substrate |
| GRAVEL | Spawning on gravel substrate |
| SAND | Spawning on sand substrate |
| SILT_CLA | Spawning on silt/clay substrate |
| HARD_PAN | Spawning on hard pan substrate |
| DETRITUS | Spawning on detritus substrate |
| VEGETANA | Adult/juvenile use of vegetation as cover |
| ALGAEA | Adult/juvenile use of algae as cover |
| WOODA | Adult/juvenile use of wood as cover |
| SUBSTRTA | Adult/juvenile use of substrate as cover |
| OVERHEDA | Adult/juvenile use of overhead cover |
| TURBIDYA | Adult/juvenile turbidity tolerance |
| POOLA | Adult/juvenile use of pools |
| RIFFLEA | Adult/juvenile use of riffles |
| RUNA | Adult/juvenile use of runs |
| RAPIDA | Adult/juvenile use of rapids |

To determine which of the ecological and life history variables were statistically significant between species at risk and species not at risk, the Mann-Whitney test for nonparametric data was used (Zar, 1984). STATUS1 was used as the grouping variable for this test. The four continuous variables were excluded from this test in their raw form, but the log-transformed continuous variables were included. All resulting test statistics were recorded, with the adjusted $p$-value of 0.05 used to determine significance.

To determine the statistical weights of the ecological and life history characteristics, a standard linear logistic regression was then run using STATUS1 as the dependent variable. The regression was used to determine the weighted parameter estimates of each variable included in the analysis (Zar, 1984). Rather than include all the ecological and life history variables, only the variables found to be significant in the Mann-Whitney test were entered into the logistic regression. The log-transformed continuous variables that were significant in the Mann-Whitney test were standardized before inclusion in the logistic regression. Standardizing the data was achieved by re-calculating the data within the variable so that the mean of the data was 0 with a standard deviation of 1. The $y$-intercept value was recorded along with the parameter estimates for each variable tested to generate the equation of the logistic regression model

To determine which variables were significant according to the number of jurisdictions a species was listed by, multiple regression was calculated using STATUS2 as the dependent variable and the significant categorical and continuous variables from the Mann-Whitney test as the independent variables. The multiple regression is used in the case that the test variable has continuous data, as opposed to the logistic regression where the test variable has only two-state data (Zar, 1984). The regression was set up as a forward stepwise model. The *y*-intercept value and parameter estimates for all variables included were recorded to define the model equation. The plot and table of observed versus predicted values were recorded along with the output table of the multiple regression.

To determine which ecological and life-history characteristics were significant based on species' highest (STATUS3) and mode (STATUS4) rankings, a Kruskal-Wallis nonparametric ANOVA was used. The Kruskal-Wallis ANOVA tests for significance between distributions of two samples, having a grouping variable that was recorded in a rank order (Zar, 1984). It was run twice, once with STATUS3 and once with STATUS4 as the grouping variables. The Kruskal-Wallis ANOVA analyzes independent variables one-at-a-time to test significance of the grouping variable. Sample size (n), H-score, *p*-value, and median were recorded for all independent variables.

To develop a statistical model capable of determining correct and incorrect classifications of fishes and a model capable of re-classifying species based on the independent variables, standard and stepwise discriminant function analyses were used. Analyses were run using STATUS3 and STATUS4 as the dependent variables, one at a time. Based on the two dependent variables, the discriminant function analysis determines the likelihood of a species being ranked properly and re-ranks species that it determines are improperly ranked. All independent variables were included in the initial analyses. The groups within the dependent variables are separated and reordered based on the characteristics within the independent variables (Manly, 1994). Classification matrices, posterior probabilities, and summaries of variables were recorded.

# 3.0. Results

Throughout the Great Lakes basin, 81 of 166 (48.8%) native species were assigned a conservation status by the 16 jurisdictions within the basin (Appendix B). Based on the non-NHIC rankings, the most frequently listed species was the lake sturgeon (*Acipenser fulvescens*), which was listed by all 9 governmental jurisdictions, with its mode rank being endangered. The family Salmonidae contained the most at-risk fishes in the Great Lakes basin. Of the 14 native salmonid species, 5 species have a mode rank of extirpated, and all 14 (100%) species have been assigned a conservation status by at least one jurisdiction. The family Cyprinidae has the highest number of native species within the basin (50), of which 20 (40%) have been assigned a conservation status by at least one jurisdiction. The ten most often ranked species are given conservation statuses by nine or more jurisdictions (Table 5).

Distribution maps were created for each of the 80 at-risk species within the Great Lakes basin. The maps display the presence or absence of each species within each watershed (Appendix C).

Frequency tables were generated by cross-tabulation for each of the 56 categorical ecological and life-history variables. The tables were made by subsets of variables rather than one large table (Appendix D).

Table 5. The ten most frequently ranked species at-risk in the Great Lakes basin. The number of rankings includes all 16 conservation agencies in the basin.

| Species | Common Name | Frequency |
|---|---|---|
| *Acipenser fulvescens* | lake sturgeon | 15 |
| *Notropis anogenus* | pugnose shiner | 12 |
| *Ammocrypta pellucida* | eastern sand darter | 12 |
| *Polyodon spathula* | paddlefish | 11 |
| *Moxostoma carinatum* | river redhorse | 11 |
| *Coregonus zenithicus* | shortjaw cisco | 11 |
| *Coregonus kiyi* | kiyi | 10 |
| *Erimystax x-punctatus* | gravel chub | 9 |
| *Machrybopsis storeriana* | silver chub | 9 |
| *Noturus stigmosus* | northern madtom | 9 |

Kolmogorov-Smirnov tests for normality indicated that no variables, including the continuous variables in raw form, had a normal distribution ($p < 0.01$) (Appendix E). Similar results were obtained from the Shapiro-Wilk test. After proving not to be normally distributed, the four continuous variables were log-transformed and re-tested for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. None of the four transformed variables exhibited normality. Although normality was not achieved by the log-transformation, the standard deviation between the means of the four normalized variables was 2.1968, as opposed to the standard deviation of the raw continuous variables, which was 165.8880. These variables were then within a similar range of deviation as the categorical variables. No ecological and life-history variables were normally distributed. Therefore, nonparametric tests were used in subsequent statistical analyses.

In the Spearman correlations, the critical value for $n$ =166 and $p$ = 0.05 was determined to be 0.152 (Zar, 1984). In the adult feeding correlation matrix, the following pairs of variables showed significant positive correlation: BO, GR; BO, SO; BO, CR; BO, AN; BO, MO; BO, IN; PE, SU; PE, FI; PE, PU; PE, AM; PE, FI2; PE, OT; SU, PU; SU, AM; SU, IN; SU, FI2; SU, OT; GR, CR; GR, IN; SO, MA; ST, AM; ST, FI2; ST, OT; PU, IN; PU, FI2; AM, FI2; AM, OT; PH, MA; CR, MO; CR, IN; AN, MO; AN, IN; AN, FI2; MO, IN; FI2, OT. The following pairs of variables showed significant negative correlation: BO, PE; BO, SU; BO, NO; BO, AM; BO, FI2; BO, PA; PE, SO; PE, MO; NO, GR; NO, CR; NO, IN; GR, SO; GR, AM; GR, PA; SO, PU; ST, IN; PU, PH; PU, MA; AM, CR; AM, IN; PH, IN; PH, FI2; MA, FI2; CR, PA; CR, OT; IN, PA; IN, OT (Appendix F).

For the adult habitat correlation matrix, the following pairs of variables showed significant positive correlation: LAKE, VEGETANA; LAKE, WOODA; STREAM, VEGETANA; STREAM, RIFFLEA; STREAM, RUNA; VEGETANA, ALGAEA; WOODA, SUBSTRTA; WOODA, OVERHEDA; SUBSTRTA, OVERHEDA; OVERHEDA, RIFFLEA; OVERHEDA, RUNA; POOLA, RUNA; RIFFLEA, RUNA. The following pairs of variables showed significant negative correlation: LAKE, STREAM; LAKE, SUBSTRTA; LAKE, RIFFLEA; VEGETANA, OVERHEDA (Appendix F).

For the spawning depth and flow regime correlation matrix, the following pairs of variables showed significant positive correlation: DEPTH1, DEPTH2; DEPTH1, DEPTH3; DEPTH2, DEPTH3; DEPTH2, DEPTH4; DEPTH3, DEPTH4; DEPTH4, DEPTH5; RIFFLES, RAPIDS. The following pairs of variables showed significant negative correlation: DEPTH2, DEPTH5; DEPTH5, RIFFLES; POOLS, RIFFLES (Appendix F).

For the spawning behavior and habitat correlation matrix, the following pairs of variables showed significant positive correlation: VEGETANS, ALGAES; VEGETANS, WOODS; VEGETANS, DETRITUS; WOODS, SUBSTRTS; WOODS, OVERHEDS; SUBSTRTS, BOULDER; SUBSTRTS, COBBLE; OVERHEDS, HARD_PAN; BEDRCKS, BOULDER; BEDRCKS, COBBLE; BOULDER, COBBLE; BOULDER, GRAVEL; COBBLE, RUBBLE; COBBLE, GRAVEL; RUBBLE, GRAVEL; GRAVEL, SAND; SAND, SILT_CLA; SILT_CLA, DETRITUS. The following pairs of variables showed significant negative correlation: VEGETANS, RUBBLE; VEGETANS,

GRAVEL; WOODS, RUBBLE; WOODS, GRAVEL; RUBBLE, SILT_CLA (Appendix F).

The correlation matrix showed strong significant positive correlations between all four continuous variables in the matrix at $n = 156$, $p < 0.05$, critical value $r = 0.157$ (Zar, 1984) (Appendix F).

The Mann-Whitney test revealed that nine variables were significantly different for species assigned a conservation status (1) and species not assigned a status (0) (Appendix G). Species assigned a conservation status within the Great Lakes basin are more likely to have high preference for stream habitat as adults and juveniles, reproduce at larger sizes, reproduce at older ages, lack nest guarding after spawning, low preference for insects as food (insectivore), high preference for fish as food (piscivore), high preference for spawning at depths greater than 200cm, high preference for spawning on sand substrate, and high preference for wood as cover for adults and juveniles.

The Kruskal-Wallis nonparametric ANOVA for grouping variable STATUS3 revealed that six variables were significantly different ($p \leq 0.05$) between the five groups within STATUS3 (0, 1, 2, 3, 4) (Appendix H). Adult and juvenile use of stream habitat, nest guarding after spawning, preference for insects as food, parasitic feeding, length at reproduction, and age at reproduction differed significantly when comparing species not at risk and species at risk at their highest conservation rank level. Using STATUS4 as the grouping variable, the Kruskal-Wallis ANOVA found ten variables to be significant when comparing species not at risk to species at risk at their mode conservation ranking (Appendix I). The STATUS4 ANOVA found spawning at depth greater than 200cm, use of runs (medium flow velocity) during spawning, maximum age, and maximum length as well as the six significant variables from the STATUS3 ANOVA to be significant between groups.

A linear logistic regression model based on grouping variable STATUS1 was developed using the nine variables that were found to be significant in the Mann-Whitney test (Table 6a). The probability of being assigned a conservation rank was determined by these variables in the following order (most to least important): spawning at depth greater than 200cm, use of stream habitat as adult and juvenile, spawning on sand substrate, preference for fish as food, age at reproduction, use of wood as cover for adult and juvenile, length at reproduction, preference for insects as food, spawning behavior (BALON_GUILD). At a decision level of 50%, the probability of species at risk being classified as at-risk by this model was 56.2%, and not at risk was 76.8% (Table 6b). Overall, species at risk and not at risk were correctly classified by this logistic regression model in 72.9% of cases (113 of 155). This logistic regression model excluded 11 species from consideration in the model due to missing data. Observed and predicted values for each species included in the logistic regression are presented in Appendix J.

Stepwise multiple regression based on grouping variable STATUS2 resulted in a model that consisted of five of the nine significant Mann-Whitney variables entered into the regression (Table 7). The probability of correctly predicting the number of jurisdictions in which a species is ranked was determined by these variables in the following order (most to least important): spawning at depth greater than 200cm, use of stream habitat as adult and juvenile, age at reproduction, preference for fish as food, spawning on sand substrate. The multiple regression model (Appendix K) returned an $R$ –value of 0.3943 for the five included variables.

Table 6a. Linear logistic regression results based on the nine variables significant in the Mann-Whitney tests.

| Model | Equation | *p* | -2LogL |
|---|---|---|---|
| 1 | Logit (p) = -1.549 + 0.911 STREAM - 0.005 BALON_GUILD + 0.068 REPLENL + 0.400 REPAGEL + 0.043 IN + 0.481 FI2 - 0.947 DEPTH5 + 0.595 SAND + 0.110 WOODA | 0.003 | 189.4 |

Table 6b. Percentages of correct classification of Great Lakes fishes as at-risk (1) or not at-risk (0) by the linear logistic regression.

| Observed | Predicted 0 | Predicted 1 | % Correct |
|---|---|---|---|
| 0 | 63 | 19 | 76.83 |
| 1 | 32 | 41 | 56.16 |

The model correctly classified 22.2% of cases (35 of 158). As with the linear logistic regression, 11 species were excluded by the model due to missing data. Observed and predicted values for each species included in the multiple regression (Figure 2) are presented in Appendix L.

Discriminant function analysis of all independent variables based on grouping variable STATUS3 correctly classified 120 of 153 (78.4%) species included in the analysis (Appendix M). Of the not-at-risk species (Group 1), 70 (86.4%) were correctly classified, five (6.1%) were re-classified as threatened, four (4.9%) re-classified as endangered, and two (2.5%) re-classified as extirpated. For special concern species (Group 2), 12 (70.6%) were correctly classified, four (23.5%) were downgraded to not-at-risk, and one (5.9%) re-classified as endangered. For threatened species (Group 3), nine (52.9%) were correctly classified, four (23.5%) were downgraded to not-at-risk, three (17.6%) re-classified as endangered, and one (5.9%) re-classified as extirpated. For endangered species (Group 4), 22 (73.3%) were correctly classified, seven (23.3%) downgraded to not-at-risk, and one (3.3%) re-classified to special concern. For extirpated species (Group 5), seven (87.5%) were correctly classified and one (12.5%) was downgraded to special concern (Table 8).

Stepwise discriminant function analysis of grouping variable STATUS3 correctly classified 107 of 155 (69.0%) species included in the analysis (Appendix N). The model produced one discriminant function that included 27 independent variables (Appendix O).

Table 7. Stepwise multiple regression results using STATUS2 (number of jurisdictions a species is listed by) as the grouping variable.

| Model | Equation | *p* | R |
|---|---|---|---|
| 1 | $\hat{Y}$ = 1.852 – 0.858 DEPTH5 + 0.332 FI2 + 0.383 REPAGEL + 0.297 SAND + 0.385 STREAM | 0.0001 | 0.3943 |

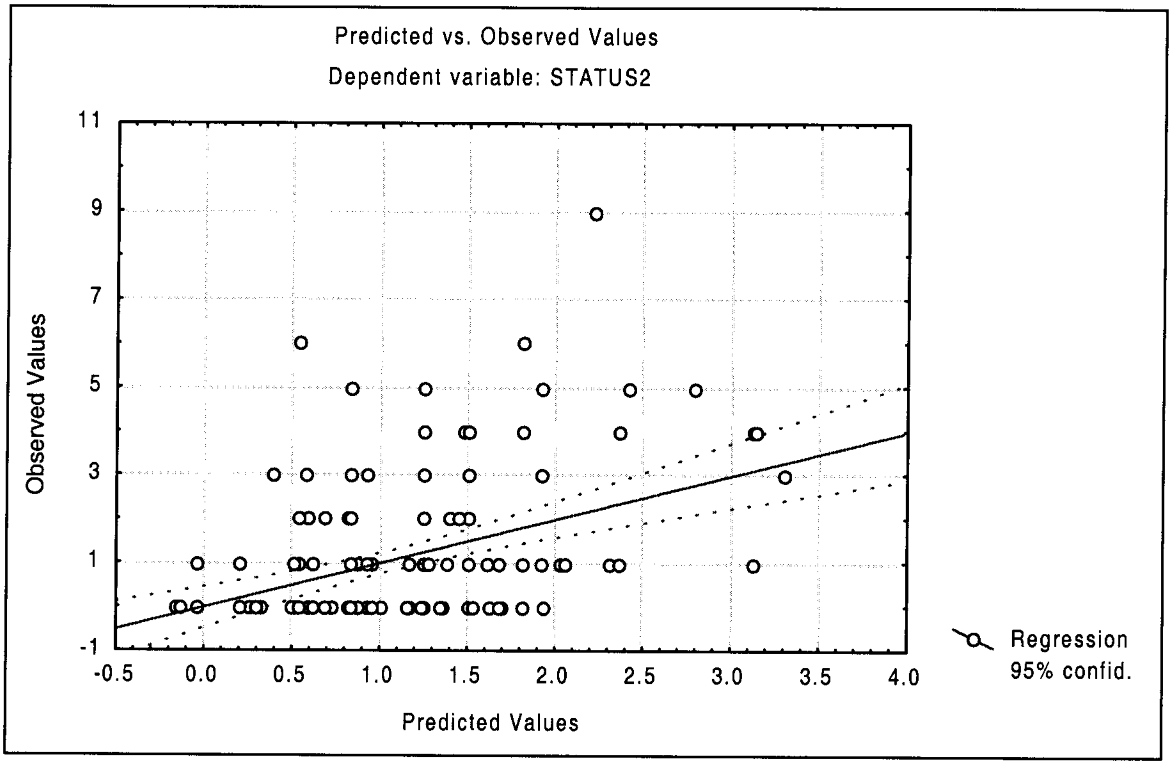


Figure 2. Plot of observed versus predicted values from the stepwise multiple regression. Predicted values that fell between discrete values were rounded to the nearest discrete value.

For species not-at-risk, 73 (89.0%) were correctly classified, two (2.4%) re-classified as threatened, six (7.3%) re-classified as endangered, and one (1.2%) re-classified as extirpated. For special concern species, 11 (64.7%) were correctly classified, five (29.4%) downgraded to not-at-risk, and one (5.9%) re-classified as endangered. For threatened species, four (23.5%) were correctly classified, 11 (64.7%) downgraded to not-at-risk, one (5.9%) re-classified as endangered, and one (5.9%) re-classified as extirpated. For endangered species, 14 (45.2%) were correctly classified, 14 (45.2%) downgraded to not-at-risk, two (6.5%) re-classified as special concern, and one (3.2%) re-classified as threatened. For extirpated species, five (62.5%) were correctly classified, two (25.0%) downgraded to not-at-risk, and one (12.5%) re-classified as special concern (Table 9).

Discriminant function analysis for all independent variables based on grouping variable STATUS4 correctly classified 122 of 153 (79.7%) species included in the analysis (Appendix P). Of the species regarded as not-at-risk, 70 (86.4%) were correctly classified, one (1.2%) re-classified as special concern, five (6.2%) re-classified as threatened, four (4.9%) re-classified as endangered, and one (1.2%) re-classified as extirpated. For special concern species, 18 (78.3%) were correctly classified and five (21.7%) downgraded to not-at-risk. For threatened species, 12 (63.2%) were correctly classified, six (31.6%) downgraded to not-at-risk, and one (5.3%) re-classified as endangered. For endangered species, 17 (70.8%) were correctly classified, four (16.7%) downgraded to not-at risk, one (4.2%) re-classified as special concern, and two (8.3%) re-classified as threatened. For extirpated species, five (83.3%) were correctly classified and one (16.7%) was re-classified as special concern (Table 10).

Table 8. Re-classifications of conservation statuses of Great Lakes fishes by the discriminant function of STATUS3. The table summarizes the number of fish species in each category that retained their current rank or had their rank changed
0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated).

| Observed | % Correct | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| 0 | 86.420 | 70 | 0 | 5 | 4 | 2 |
| 1 | 70.588 | 4 | 12 | 0 | 1 | 0 |
| 2 | 52.941 | 4 | 0 | 9 | 3 | 1 |
| 3 | 73.333 | 7 | 1 | 0 | 22 | 0 |
| 4 | 87.500 | 0 | 1 | 0 | 0 | 7 |
| Total | 78.431 | 85 | 14 | 14 | 30 | 10 |

Table 9. Re-classifications of conservation statuses of Great Lakes fishes by the stepwise discriminant function of STATUS3. The table summarizes the number of fish species in each category that retained their current rank or had their rank changed (0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated).

| Observed | % Correct | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| 0 | 89.024 | 73 | 0 | 2 | 6 | 1 |
| 1 | 64.706 | 5 | 11 | 0 | 1 | 0 |
| 2 | 23.529 | 11 | 0 | 4 | 1 | 1 |
| 3 | 45.161 | 14 | 2 | 1 | 14 | 0 |
| 4 | 62.500 | 2 | 1 | 0 | 0 | 5 |
| Total | 69.032 | 105 | 14 | 7 | 22 | 7 |

Stepwise discriminant function analysis of grouping variable STATUS4 correctly classified 102 of 158 (64.6%) species included in the analysis (Appendix Q). The model produced one discriminant function that included 21 independent variables (Appendix R). For species not-at-risk, 73 (85.9%) were correctly classified, two (2.4%) re-classified as special concern, three (3.5%) re-classified as threatened, six (7.1%) re-classified as endangered, and one (1.2%) re-classified as extirpated. For special concern species, 14 (58.3%) were correctly classified, eight (33.3%) downgraded to not-at-risk, one (4.2%) re-classified as threatened, and one (4.2%) re-classified as endangered. For threatened species, three (15.8%) were correctly classified, 14 (73.7%) downgraded to not-at-risk, and two (10.5%) re-classified as extirpated. For endangered species, nine (37.5%) were correctly classified, ten (41.7%) downgraded to not-at-risk, four (16.7%) re-classified as special concern, and one (4.2%) re-classified as threatened. For extirpated, three (50.0%) were correctly classified, two (28.6%) downgraded to not-at-risk, and one (14.3%) re-classified as special concern (Table 11).

Table 10. Re-classifications of conservation statuses of Great Lakes fishes by the discriminant function of STATUS4. The table summarizes the number of fish species in each category that retained their current rank or had their rank changed (0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated).

| Observed | % Correct | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| 0 | 86.420 | 70 | 1 | 5 | 4 | 1 |
| 1 | 78.261 | 5 | 18 | 0 | 0 | 0 |
| 2 | 63.158 | 6 | 0 | 12 | 1 | 0 |
| 3 | 70.833 | 4 | 1 | 2 | 17 | 0 |
| 4 | 83.333 | 0 | 1 | 0 | 0 | 5 |
| Total | 79.739 | 85 | 21 | 19 | 22 | 6 |

Table 11. Re-classifications of conservation statuses of Great Lakes fishes by the stepwise discriminant function of STATUS4. The table summarizes the number of fish species in each category that retained their current rank or had their rank changed (0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated).

| Observed | % Correct | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| 0 | 85.882 | 73 | 2 | 3 | 6 | 1 |
| 1 | 58.333 | 8 | 14 | 1 | 1 | 0 |
| 2 | 15.789 | 14 | 0 | 3 | 0 | 2 |
| 3 | 37.500 | 10 | 4 | 1 | 9 | 0 |
| 4 | 50.000 | 2 | 1 | 0 | 0 | 3 |
| Total | 64.557 | 107 | 21 | 8 | 16 | 6 |

# 4.0. Discussion

### *4.1. Hypothesis*

It was predicted that the statistical analyses would show that *K*-selected life-history traits were significant for at-risk fishes. Two of the most important characteristics of *K*-selected species were found to be significant in several tests. Length at reproduction was significant in six tests, and age at reproduction was significant in five tests. Maximum age was found to be significant in three tests and maximum length was found to be significant in one test. Each of the *K*-selected traits included in the master database was found to have be significant in at least one test, suggesting that species possessing *K*-selected traits are more likely to be at risk. According to the master database, 45 species have life spans of ten or more years. Prior to the analyses, 25 (55.6%) of those species were considered to be at-risk. According to the re-classifications by the standard discriminant function analysis of STATUS3, only five (11.1%) were re-classified as not-at-risk. For the re-classifications by the standard discriminant function analysis of STATUS4, only three (6.7%) were re-classified as not-at-risk, and five (11.1%) previously not-at-risk species were re-classified as at-risk. Therefore, the results suggest an increased likelihood of decline for fishes in the Great Lakes basin possessing *K*-selected traits and the hypothesis was not rejected.

### *4.2. Biological Significance*

The models suggest that Great Lakes fish species that have a preference for stream habitat during adult and juvenile life stages are at greater risk than species that prefer lake habitat. Lakes are safer habitats and can absorb small-scale changes (Parent and Schriml, 1995), such as increases in siltation, turbidity, or temperature. Because of the greater volume of lakes, they have the ability to dissipate disturbances, so parts of the lake may never feel the effects of a disturbance (Waters, 1995). Streams are far more susceptible to small-scale changes because the effects of those changes cannot be dispersed or absorbed across a large area. Upstream disturbances may impact downstream areas because streams have little buffering capacity to limit the downstream reach of a disturbance (Waters, 1995). Reductions in flow and water levels can force species out of critical spawning, feeding, and refuge habitat. In drought conditions, spawning habitat may not be accessible, leading to reproductive failure for that year (Jenkins and Burkhead, 1994). Such a condition would be detrimental to a species such as the lake sturgeon (*Acipenser fulvescens*) (i.e. some individuals of this species may wait several years between spawning attempts) (Becker, 1983). The reduced reproductive capacity of the population would place the species in a critical position, pushing toward extirpation.

Streams and rivers are at significant risk from human manipulation because human actions often result in direct alterations of aquatic communities (Jones et al., 1999). Streams are susceptible to impacts from agriculture, dams, urbanization, loss of riparian cover, mining, and habitat alterations from presence of bridges (Waters, 1995). Small areas that are directly impacted may be highly sensitive areas for fishes. Critical spawning grounds, nurseries, and adult feeding habitats can be destroyed. These habitat alterations may indirectly affect downstream areas as well. Dams may prevent species, such as the black redhorse (*Moxostoma duquesnei*) (Jenkins and Burkhead, 1994), from migrating upstream. Upstream deforestation can cause increased turbidity downstream, forcing species with low turbidity tolerance, such as the northern brook lamprey (*Ichthyomyzon fossor*) (Portt et al., 1999), out of critical habitat.

Many fish species, as a result of their use of a specific type of cover, have developed a threshold for the distance between suitable cover (Jones et al., 1999). Species depend on cover for refuge from predators (e.g. Cyprinidae) (Jenkins and Burkhead, 1994), to provide hiding areas for hunting (e.g. grass pickerel, *Esox americanus vermiculatus*) (Trautman, 1981), to provide shade in slackwaters (e.g. paddlefish, *Polyodon spathula*) (Etnier and Starnes, 1993), and for cover during spawning (e.g. black bullhead, *Ameiurus melas*) (Trautman, 1981). The lack of suitable submerged woody debris within that threshold makes species with that preference more susceptible. Urbanized areas and surrounding suburbs often have programs directed toward removal of debris considered to be unsightly or inhibitory. This removal of debris may create a stream length that is beyond a species distance threshold. This would also cause populations to become fragmented and genetically isolated (Stiling, 1999). Lack of genetic variability due to isolation would severely impact a fragmented population. Repeated inbreeding within the isolated population would generate less fit offspring, and the population would die off (Stiling, 1999). Species with a greater distance threshold or with no threshold at all would be unaffected by the distances between suitable patches of submerged woody debris.

Submerged woody debris is often used by piscivores and pursuit predators, species termed lie-in-wait predators. The species, such as esocids, are morphologically adapted to hiding by floating motionless amongst the debris and darting out in a lightning-fast burst to capture the prey. These fishes count on the debris to cover them so when an attack is made, it is quick and does not require an extensive chase of the prey (Moyle and Cech, 2000). Without ideal cover, these predators suffer lower success in capturing food. Many predators of this type in the Great Lakes have a high preference for this woody debris. Prey fishes would be at significantly greater risk from predation without proper cover for refuge. Many smaller fishes, such as some minnows (Cyprinidae) and darters (Percidae), which rely on this cover would experience population declines in areas lacking sufficient cover due to exploitation from predators.

The models suggested that species preferring submerged woody debris for cover were at significantly higher risk. This woody debris can be utilized by smaller fishes as refuge from predators, or as cover for predators that feed by ambushing their prey. Loss of this cover for prey species would allow them to be easily predated. Increased predation pressure could potentially reduce the prey species' population significantly. Removal of riparian vegetation could indirectly affect species with preference for this cover. The lack of the riparian vegetation may result in lack of in-stream woody debris (Boschung and O'Neil, 1981). Conversely, lack of woody debris may indicate lack of riparian cover. This could affect thermally-sensitive species due to lack of shading. Without large riparian flora like trees, grasses, and large shrubs, agricultural runoff would be uninhibited (Waters, 1995), leading to increased turbidity and pollutant input that would significantly alter habitats (Ludsin et al., 2001). Populations of species depending on such forms of cover, such as darters (Percidae) (Jenkins and Burkhead, 1994) would likely decrease greatly from areas with riparian cover to areas without it (Jones et al., 1999).

preference for any secondary type. This strong preference significantly increases susceptibility to any form of habitat change (Francis et al., 1979). Changes in predator numbers, water temperature, dissolved oxygen, or any other environmental variable may significantly raise the odds against any eggs hatching or fry surviving to become juveniles (Stiling, 1999). Species forced to use less desirable habitat for spawning, if they will even utilize it, will increase mortality of offspring as the eggs and fry require as specialized habitats as adults (Moyle and Cech, 2000).

Most of the at-risk species demonstrate spawning and rearing behaviors that do not provide parental protection for eggs or hatched broods. These species tend to lay more eggs per spawning attempt or larger eggs (*K*-selected) to compensate for the high loss rate of eggs and high mortality of fry (Winemiller and Rose, 1992). Yet, egg-eating predators may offset the numbers of eggs. The presence of an egg-eating predator would decrease the number of eggs able to hatch, thus decreasing survivorship for a brood (Janssen and Jude, 2001). Populations of these species decline as numbers within cohort groups continually decrease, such as the case with the rapid decline of mottled sculpin (*Cottus bairdi*) populations in Calumet Harbor, Lake Michigan after the introduction of the round goby (*Neogobius melanostomus*) (Janssen and Jude, 2001).

Piscivores were found to have a higher risk level than fishes with other feeding regimes. This contradicts Parent and Schriml (1995) who found that piscivorous species were less likely to be at risk. Of the species listed as at-risk in the master database, the piscivores on the list (e.g. esocids, salmonines, spotted gar (*Lepisosteus oculatus*)) have diets which consists almost exclusively of fishes. The cause of the discrepancy between results for Parent and Schriml (1995) and the current study is likely the level of specification available in the raw data sets. Parent and Schriml (1995) only used a simple system to rank possible predators. This lack of refinement was unable to account for variation in food web levels of piscivorous fishes. They classified a fish as a piscivore if at least 25% of its diet consisted of fish, below that percentage, they were placed in one of three other groups. The current study used four categories to rank species' food preferences, which allowed for further refinement of the model. Fishes whose diets consist of low percentages of fish were given a low value, thus allowing them to be considered piscivores. Therefore, most fish species-at-risk in the Great Lakes basin have some level of preference for fish in their diets, and highly piscivorous fishes are most at-risk. The role of the piscivore variable (FI2) in this model suggests that top-level species are more at-risk than intermediate and lower food web species in the Great Lakes basin.

The majority of smaller fishes in this study (e.g. cyprinids, percids) have high preference for insects and low or no preference for fish. Since fishes that eat insects are usually smaller, they may also consume large amounts of small mollusks and annelids. The variables for consumption of insects, consumption of annelids, and consumption of mollusks were positively correlated. These characteristics were not significantly different between at-risk and not-at-risk fishes. Larger piscivores may supplement their diets by consuming insects, but have low preference for them because the overall energetic cost for capturing an insect is not warranted by the energy received from it (Elliott and Hurley, 2000). Fishes that consume insects as a primary dietary source occur lower on food webs, suggesting again that lower-level species are at less risk than top-level fishes, again rebutting Parent and Schriml (1995).

### *4.3. Species-at-Risk Profiles*

The majority of species were correctly classified by the standard and stepwise discriminant function analyses. In general, the same species were found to be incorrectly classified in all analyses. I will discuss the reasons these species are considered at-risk. In particular, I will focus on factors for their current at-risk status that were not included in the statisitcal analyses because sufficient data were not available.

Walleye (*Stizostedion vitreum vitreum*) was re-classified to extirpated from not-at-risk. The walleye is a favorite sport fish among anglers in the Great Lakes. However, walleye are not at-risk in the Great Lakes because their populations are maintained (Trautman, 1981). The blue pike *(Stizostedion vitreum glaucum)*, an extinct subspecies genetically similar to walleye endemic to the Great Lakes has been globally extinct since the 1960's (Francis et al., 1979). Blue pike were not included in the analysis because of missing data. It can be assumed, though, that blue pike would be ranked as extirpated as it has nearly identical life-history traits to walleye. However, blue pike are extinct as a direct result of overfishing. The blue pike populations were eliminated before any recovery program could be enacted (Trautman, 1981).

Overexploitation by commercial fishing has been the direct cause of declines and extirpations of many Great Lakes fishes. Along with the blue pike, lake sturgeon (*Acipenser fulvescens*) populations declined because of overfishing. Based on life-history and ecology, lake sturgeon are not at-risk. However, the species is listed by fifteen jurisdictions as at-risk. Because commercial value was not a variable in the analyses, effects of overfishing could not be accounted for. Commercial overexploitation accounts for the majority of Great Lakes salmonids being at-risk in the basin. High commercial value has led to drastic declines of lake whitefish (*Coregonus clupeaformis*), cisco (*C. artedi*), hoyi (*C. hoyi*), kiyi (*C. kiyi*), blackfin cisco (*C. nigripinnis*), deepwater cisco (*C. johannae*), shortnose cisco (*C. reighardi*), shortjaw cisco (*C. zenithicus*), pygmy whitefish (*Prosopium coulteri*), round whitefish (*P. cylindraceum*), Atlantic salmon (*Salmo salar*), lake trout (*Salvelinus namaycush*), and Arctic grayling (*Thymallus arcticus*) (Trautman, 1981).

The presence of sea lamprey (*Petromyzon marinus*) in the Great Lakes basin and their effect on individual species was unaccounted for by variables used in the analyses. Sea lamprey have impacted a wide range of fishes in the basin. Longnose sucker (*Catostomus catostomus*), spotted sucker (*Minytrema melanops*), redhorse species (*Moxostoma* spp.), lake trout (*Salvelinus fontinalis*), and burbot (*Lota lota*) have decreased in abundance due to the presence of sea lamprey (Trautman, 1981).

Habitat alterations have impacted the greatest number of species within the Great Lakes basin. Alterations to habitat have resulted in direct and indirect negative effects to native fishes. Loss of riparian cover resulted increased temperatures in streams (Waters, 1995). Cool water species, such as the northern madtom (*Noturus stigmosus*) and brook trout (*Salvelinus fontinalis*) have been forced out of critical habitat. Brook trout are listed as threatened in Ohio. Industrial and agricultural expansion led to increased water temperatures on the southern shore of Lake Erie, forcing brook trout out of those areas (Trautman, 1981). Other cool-water species, such as the silverjaw minnow (*Notropis buccatus*) and redside dace (*Clinostomus elongatus*), have had their distributions limited by increasing water temperatures (Trautman, 1981).

Eutrophication and increased turbidity in the Great Lakes basin has limited the distributions of many fishes. Eutrophication has negatively affected benthic species, such as black bullhead (*Ameiurus melas*), burbot (*Lota lota*), spoonhead sculpin (*Cottus ricei*), and deepwater sculpin (*Myoxocephalus thompsoni*) (Becker, 1983). Loss of critical habitat forced these benthic species into smaller areas, in which they were forced to compete for limited resources (Ludsin et al., 2001). Increased turbidity has forced species, such as the northern brook lamprey (*Ichthyomyzon fossor*) and silver shiner (*Notropis photogenis*), out of critical habitat and out of drainage basins altogether (Jenkins and Burkhead, 1994). Their physical adaptations to clear water make them unable to carry out normal behaviors properly, such as feeding and remaining in shoals for protection from predators (Moyle and Cech, 2000).

Habitat alterations in the form of dams, barriers, and bridges have the potential to be the greatest cause for species being at-risk (Jones et al., 1999). Loss of accessibility to critical habitat and fragmentation of populations have negatively impacted a wide spectrum of fishes. Species that migrate into streams to spawn, such as suckers (e.g. *Catostomus* spp., *Moxostoma* spp.) (Trautman, 1981), are unable to reach critical spawning habitat and suffer reduced reproductive success. Stream dwelling species of minnows (Cyprinidae) and darters (Percidae) are perhaps the groups of fishes most heavily affected by such disturbances. Their populations are easily fragmented by barriers, as they have little capability to pass over these obstructions to access upstream regions (Jenkins and Burkhead, 1994). Barriers, such as dams, also provide places for suspended sediments to build up (Waters, 1995). This build up can be extensive, and can eventually destroy critical habitats for fishes by burying preferred substrates for feeding and spawning.

### *4.4. Results in Context*

Life-history theory attempts to explain the variations in species populations through comparison of demographics and reproductive strategies relative to a variable environment (Winemiller and Rose, 1992). The current study does this and is similar to studies completed by Parent and Schriml (1995) and Morris (2002). Discrepancies were a result of different study areas and the number of categories that species' preferences could be classified as in the data used in the analyses. Parent and Schriml (1995) utilized a database that consisted of variables that had only two categories (0,1) within the variables. Morris (2002) expanded on the previous study by adding the multiple regression and discriminant function analyses. Their models proved capable of developing distinct at-risk models for fish species in the Canadian Great Lakes basin. The current study followed the database design from Morris (2002) which provided multiple categories for quantifying species' preferences for the ecological and life-history variables. Discrepancies between results of the current study and Morris (2002) are a result of changes in trends resulting from expansion of the database from 114 to 166 species. By adding more variables to the analyses, more ecological and life-history variables are likely to be found to be significant between species at-risk and not-at-risk. Also, updating the data within the variables presently being used, thereby limiting missing data, will help to make the analyses more accurate.

### *4.5. Application to Conservation*

Life-history theory provides suggestions of where attention may be focused to return efficient monitoring and research (Winemiller and Rose, 1992). Since we are able to statistically determine what ecological and life-history traits are likely to make a species at-risk, conservation efforts can be applied in proper context of those vulnerabilities to make conservation more effective. The results of this study reinforces the importance of maintaining the natural integrity of aquatic ecosystems, as well as rehabilitating habitats altered by human activities to recreate historically natural conditions that at-risk species require to thrive and reproduce successfully. It is important, however, that a conservation method be thoroughly assessed prior to being implemented so negative impacts on non-target species can be minimized. An example of this is the proposed use of barriers to prevent sea lamprey from spawning in Great Lakes tributaries. Although it may be effective at preventing sea lamprey spawning, barriers may also prevent at-risk species from reaching critical spawning grounds. Conservation should be carried out at the ecosystem level, as opposed to species-by-species because efforts for preservation or restoration for one species may have unanticipated negative effects on others (Winemiller and Rose, 1992).

The results of this study suggest many broad approaches to conservation of fishes in the Great Lakes basin. Based on the consistent appearance of preference for stream habitat throughout the analyses, conservation efforts should be focused on stream habitats. Debris should not be removed from stream banks for species that need it as cover (e.g. longnose sucker, *Catostomus catostomus*) (Becker, 1983) and sediments, such as sand, should not be mined from stream beds for species that require it for spawning (e.g. golden redhorse, *Moxostoma erythrurum*) (Jenkins and Burkhead, 1994). Also, diversion of water out of the stream should be limited. By preventing such habitat alterations, all species within the stream ecosystem will be able to thrive. Based on the data from this study, it could be suggested that any species that spends the majority of its life in a stream habitat should be considered at-risk. Although lakes should not be regarded as safe habitats, because of the susceptibility of streams to disturbances, stream ecosystems should be the primary concern of conservation efforts.

### *4.6. Limitations of Analyses*

The major limiting factor of the analyses was the availability and reliability of data. Not all aspects of a species' life history are known. Except for species commonly studied, such as fishes with economic importance, many smaller fishes with little or no direct economic value have poorly understood ecology. In the current study, cyprinids lacked the most data. Often, sources would simply say that little is known about their life history. In most cases, the species have never been adequately studied. Their life histories are typically assumed to be similar to closely related species. Understanding the ecology of the 166 species native to the Great Lakes basin is not likely to happen in the near future, so such assumptions must be made in order to carry out ecological analyses.

The question then arises: how reliable are the data if a large number of the values are based on assumptions? Although basic ecological information for each species would be preferred, basing assumptions on similar species is the most reliable means for reducing the amount of missing data. Species within the same genus or family will often exhibit similar life-history and ecological traits (Duncan and Lockwood, 2001). These characteristics can be used to fill in missing data for similar species. However, by doing so, there is a trade-off between the completeness of the analyses and the accuracy of the predictions for each species. If a species' preference for some variable is incorrectly categorized based on a species in the same genus, then the predicted at-risk status for that unknown species may be incorrect, being either too high or too low. Conversely, if missing data are allowed to remain so that incorrect classifications are avoided, then a large number of species will be excluded from the statistical tests based on the amount of missing data.

The analyses, despite their limitations are not limited to use only within the Great Lakes basin, but may be used for any fish community. The reliability of each study will depend on the validity and availability of data for the species included in the study. These analyses would be most effective for fish communities for which there are extensive data for life history and ecology for each species.

### *4.7. Conclusions*

Predicting which fish species in the Great Lakes basin are at-risk and require protection may be one of the most difficult tasks yet in conservation biology (Russell et al., 1999). However, statistical tests can provide reliable insights into such a problem. Statistical tests can generate models that predict actual conditions. However, the degree of accuracy to which the models can successfully predict those actual conditions is limited by the accuracy of the data entered. The reliability of the results is directly proportional to the quality of the raw data provided (Duncan and Lockwood, 1992). By further refining data and repeating the analyses over again, the validity and success of the current study can then be determined.

*K*-selected species were found to be more at-risk than *r*-selected species, so the hypothesis was not rejected. At-risk and not-at-risk fish species in the Great Lakes basin were found to be significantly different based on a subset of ecological and life-history characteristics. In most statistical tests, variables from that subset were repeatedly found to be significant. The results indicated that fish species-at-risk in the Great Lakes basin have a high preference for stream habitat as adults and juveniles, low preference for insects as food, high preference for fish as food, high preference for woody debris for cover as adults and juveniles, high preference for spawning on sand substrate, high preference for spawning at depth greater than 200cm, reproduce at older ages and larger sizes, and do not exhibit parental care. Although no species fit this profile exactly, several species classified as at-risk exhibit several of these characteristics in their ecology and life-history.

The current study has provided further insight into the likely factors that contribute to the at-risk status of fishes in the Great Lakes basin. The models used in past studies, such as Parent and Schriml (1995), Duncan and Lockwood (2001), and Morris (2002), provided a framework from which to attempt the first basin-wide ecological analysis of Great Lakes fishes. With the results of the current and past studies, conservation efforts for Great Lakes fishes can become concentrated on areas where they are more likely to have a greater positive impact on preserving the unique aquatic ecosystems and biodiversity within the Great Lakes basin.

## References


Balon, E.K. 1975. Reproductive guilds of fishes: a proposal and definition. *Journal of the Fisheries Research Board of Canada* 32: 821-864.

Balon, E.K. 1981. Additions and amendments to the classification of reproductive styles in fishes. *Environmental Biology of Fish* 6 (3/4): 377-389.

Becker, G.C. 1983. *Fishes of Wisconsin*. University of Wisconsin Press, Madison, WI.

Blatchley, W.S. 1938. *The fishes of Indiana*. Nature Publishing, Indianapolis, IN.

Bogue, M.B. 2000. *Fishing the Great Lakes*. University of Wisconsin Press, Madison, WI.

Boschung, H. and P. O'Neil. 1981. The effects of forest clear-cutting on fishes and macroinvertebrates in an Alabama stream. *American Fisheries Society: Warmwater Streams Symposium,* L.A. Krumholz, ed.: 200-217.

Coker, G.A., C.B. Portt and C.K. Minns. 2001. Morphological and ecological characteristics of Canadian freshwater fishes. *Canadian Manuscript Report of Fishes and Aquatic Sciences* 2554.

Coon, T.G. 1999. *Ichthyofauna of the Great Lakes basin*. In Great Lakes Fisheries Policy and Management: a Binational Perspective. W.W. Taylor and C.P. Ferreri, eds. Michigan State University Press, East Lansing.

Cooper, E.L. 1983. *Fishes of Pennsylvania and the northeastern United States*. Pennsylvania State University Press, University Park, PA.

Daniels, R.A. 2001. Untested assumptions: the role of canals in the dispersal of sea lamprey, alewife, and other fishes in the eastern United States. *Environmental Biology of Fishes* 60 (4): 309-329.

Djuricich, P. and J. Janssen. 2001. Impact of round goby predation on zebra mussel size and distribution at Calumet Harbor, Lake Michigan. *Journal of Great Lakes Research* 27 (3): 312-318.

Duncan, J.R. and J.L Lockwood. 2001. Extinction in a field of bullets: a search for causes in the decline of the world's freshwater fishes. *Biological Conservation* 102: 97-105.

Elliott, J.M. and M.A. Hurley. 2000. Optimum energy intake and gross efficiency of energy conversion for brown trout, *Salmo trutta*, feeding on invertebrates or fish. *Freshwater Biology* 44 (4): 605-615.

Etnier, D.A. and W.C. Starnes. 1993. *The fishes of Tennessee.* University of Tennessee Press, Knoxville, TN.

Francis, G.R., J.J. Magnuson, H.A. Reiger and D.R. Talhelm (eds.). 1979. Rehabilitating Great Lakes ecosystems. *Great Lakes Fishery Commission Technical Report No. 37.*

Honeyfield, D.C. and J.P. Hinterkopf. 2002. Isolation of thiaminase-positive bacteria from alewife. *Transactions of the American Fisheries Society* 131 (1): 171-175.

Idrisi, N., E.L. Mills and L.G. Rudstam. 2001. Impact of zebra mussels (*Dreissena polymorpha*) on the lower trophic levels of Oneida Lake, New York. *Canadian Journal of Fisheries and Aquatic Sciences* 58 (7): 1430-1441.

Janssen, J. and D.J. Jude. 2001. Recruitment failure of mottled sculpin (*Cottus bairdi*) in Calumet Harbor, southern Lake Michigan, induced by the newly introduced round goby (*Neogobius melanostomus*). *Journal of Great Lakes Research* 27 (3): 319-328.

Jenkins, R.E. and N.M. Burkhead. 1994. *Freshwater fishes of Virginia.* American Fisheries Society, Bethesda, MD.

Jennings, S., J.D. Reynolds and N.V.C. Polunin. 1999. Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life-histories. *Conservation Biology* 13 (6): 1466-1475.

Johnson, D.A. , J.W.Weisser and T.D. Bills. 1999. Sensitivity of lake sturgeon *(Acipenser fulvescens)* to the lampricide 3-triflouromethyl-4-nitrophenol (TFM) in field and lab exposures. *Great Lakes Fishery Commission Technical Report* No. 62: 1-23.

Jones, D.E.B. III, G.S. Helfman, J.O. Harper and P.V. Bolstad. 1999. Effects of riparian forest removal on fish assemblages on southern Appalachian streams. *Conservation Biology* 13 (6): 1454-1465.

Kilgour, B.W., R.C. Bailey and T.E. Howell. 2000. Factors influencing changes in the nearshore benthic community on the Canadian side of Lake Ontario. *Journal of Great Lakes Research* 26 (3): 272-286.

King, E.L. Jr. and J.A. Gabel. 1986. Comparative toxicity of the lampricide 3-triflouromethyl-4-nitrophenol to ammocoetes of three species of lamprey. *Great Lakes Fishery Commission Technical Report No. 47*: 1-5.

Lande, R. 1988. Genetics and demography in biological conservation. *Science (Washington D.C.)* 241: 1455-1460.

Ludsin, S.A., M.W. Kershner, K.A. Blocksom, R.L. Knight and R.A. Stein. 2001. Life after death in Lake Erie: nutrient controls drive fish species richness, rehabilitation. *Ecological Applications* 11 (3): 731-746.

Manly, B.F.J. 1994. *Multivariate statistical methods*. Second Edition. Chapman and Hall, London.

Morris, T.J. 2002. Ecological models for determining fish species at risk in Canada. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* (unpublished manuscript).

Moyle, P.B. and J.J Cech. 2000. *Fishes: an introduction into ichthyology*. Fourth Edition. Prentice Hall, Upper Saddle River, NJ.

Parent, S. and L.M. Schriml. 1995. A model for the determination of fish species at risk based upon life-history traits and ecological data. *Canadian Journal of Fisheries and Aquatic Sciences* 52: 1768-1781.

Portt, C.B., G.A. Coker and C.K. Minns. 1999. Riverine habitat characteristics of fishes of the Great Lakes watershed. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* 2481.

Robinson, H.W. and T.M. Buchanan. 1988. *Fishes of Arkansas*. University of Arkansas Press, Fayetteville, AR.

Russell, G.J., T.M. Brooks, M.L. McKinney and C.G. Anderson. 1999. Present and future taxonomic selectivity in bird and mammal extinctions. *Conservation Biology* 12: 1365-1376.

Scott, W.B. and M.G. Scott. 1988. *Atlantic fishes of Canada*. University of Toronto Press, Toronto, ON.

Smith, C.L. 1985. *The inland fishes of New York state*. New York Department of Environmental Conservation, Albany, NY.

Smith, P.W. 1979. *The fishes of Illinois*. University of Illinois Press, Urbana, IL.

StatSoft, Inc. 1997. Statistica for Windows, release 5.0. StatSoft, Inc., Tulsa, OK.

Stiling, P. 1999. *Ecology: theories and applications.* Third Edition. Prentice-Hall, Inc., Upper Saddle River, NJ.

Trautman, M.B. 1981. *The fishes of Ohio.* The Ohio State University Press, Columbus, OH.

Waters, T.F. 1995. *Sediment in streams.* American Fisheries Society, Monograph 7, Bethesda.

Wilson, D.S. 1997. Biological communities as functionally organized units. *Ecology (Washington D.C.)*: 2018-2024.

Winemiller, K.O. and K.A. Rose. 1992. Patterns of life-history diversification in the North American fishes: implications for population regulation. *Canadian Journal for Fisheries and Aquatic Sciences* 49: 2196-2218.

Zar, J.H. 1996. *Biostatistical analysis*; second ed. Prentice-Hall, Inc., Englewood Cliffs, CA.

Appendix A. Definitions for the reproductive guilds attributed to fishes of the Great Lakes basin (Balon ,1975, 1981).

| Guild code | Category for Current Study | Guild name | Description |
|---|---|---|---|
| A.1.1 | 1 | Nonguarders: Open substratum spawners: Pelagophils | Large quantities of non-adhesive, near-neutral or positively buoyant eggs are released and scattered in open water. No parental care of eggs. |
| A.1.2 | 2 | Nonguarders: Open substratum spawners: Litho-pelagophils | Eggs are deposited on rocks and gravel, but the eggs, eleutheroembryos, or larvae become sufficiently buoyant to be carried away from the spawning substrate by water currents. No parental care of eggs. |
| A.1.3 | 3 | Nonguarders: Open substratum spawners: Lithophils | Deposit eggs on a rock, rubble, or gravel bottom where their embryos and larvae develop. No parental care of eggs. |
| A.1.4 | 4 | Nonguarders: Open substratum spawners: Phyto-lithophils | Deposit eggs in relatively clearwater habitats on submerged plants, if available, or on other submerged items such as rocks, logs, or gravel, where their embryos and larvae develop. No parental care of eggs. |
| A.1.5 | 5 | Nonguarders: Open substratum spawners: Phytophils | Scatter or deposit eggs with an adhesive membrane that sticks to submerged, alive or dead, aquatic plants, or to recently flooded terrestrial vegetation. Sometimes on logs and branches. No parental care of eggs. |
| A.1.6 | 6 | Nonguarders: Open substratum spawners: Psammophils | Usually small eggs with an adhesive membrane that are scattered directly on sand and/or the fine roots of plants that hang over the sandy bottom. No parental care of eggs. |
| A.2.3 | 7 | Nonguarders: Brood hiders: Lithophils | Eggs are hidden in specially constructed places. In most cases the hiding places (called redds in salmonids) are excavated in gravel by the female. No parental care of eggs. |
| B.1.3 | 8 | Guarders: Substratum choosers: Lithophils | Choose rocks for attachment of their eggs. Eggs are guarded, and possibly cleaned and ventilated. |
| B.1.4 | 9 | Guarders: Substratum choosers: Phytophils | Choose plants for attachment of their eggs. Eggs are guarded, and possibly cleaned and ventilated. |

| | | | |
|---|---|---|---|
| B.2.2 | 10 | Guarders: Nest spawners: Polyphils | No particular nest building material or substrate is chosen, however, a nest is constructed and the nest and eggs are guarded. |
| B.2.3 | 11 | Guarders: Nest spawners: Lithophils | Eggs are deposited on cleaned areas of rocks or in pits dug in gravel, however, numerous deviations from this simple scheme have been recorded. All nests are guarded. |
| B.2.4 | 12 | Guarders: Nest spawners: Ariadnophils | The nest building male has the ability to spin a viscid thread from a kidney secretion, which binds the nest of different material together. The eggs are guarded and ventilated by the male, who also guards the young once they hatch. |
| B.2.5 | 13 | Guarders: Nest spawners: Phytophils | Eggs are deposited in nests constructed above or on a soft muddy bottom, often amid algae or the exposed roots of vascular plants, however, there are numerous deviations from this scheme. All nests are guarded. |
| B.2.7 | 14 | Guarders: Nest spawners: Speleophils | These fishes guard a clutch of eggs in natural holes or cavities, in specially constructed burrows, or where deposited on a cleaned area of the undersurface of flat stones. |

## Species At Risk in the Great Lakes Basin

The following list of fish species are listed as endangered, threatened, extripated, extinct, vulnerable, and/or special concern/interest or are assigned a Natural Heritage Information Centre ranking by the US states and the Canadian province of the Great Lakes basin

| Scientific Name by Order and Family | International | | Canada | | Status by State/Province/Organization United States | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | GCR``` | IUCN`` | Ontario NHIC | COSEWIC` | Illinois state | Indiana state | Michigan state | Michigan NHIC | Minnesota state | New York state | New York NHIC | Ohio state | Pennsylvania state | Pennsylvania NHIC | Wisconsin state | Wisconsin NHIC |
| **Petromyzontiformes** | | | | | | | | | | | | | | | | |
| **Petromyzontidae** | | | | | | | | | | | | | | | | |
| *Ichthyomyzon castaneus* | G5 | | | SC | | | | | | | | | | | | |
| *Ichthyomyzon fossor* | G4 | | S3 | SC | END | | | | SC | | S1 | END | END | S1 | | |
| *Ichthyomyzon unicuspis* | G5 | | S3 | | | | | | | | | | | SH | | |
| *Lampetra appendix* | G4 | | S3 | | | | | | | | | | | S3 | | |
| **Acipenseriformes** | | | | | | | | | | | | | | | | |
| **Acipenseridae** | | | | | | | | | | | | | | | | |
| *Acipenser fulvescens* | G3 | VUL | S3 | | END | END | THR | S2 | SC | THR | S1 | END | END | S1 | SC | S3 |
| **Polyodontidae** | | | | | | | | | | | | | | | | |
| *Polyodon spathula* | G4 | VUL | SX | EXP | | | EXP | SX | THR | | SX | THR | | SXSC | THR | S2? |
| **Lepisosteiformes** | | | | | | | | | | | | | | | | |
| **Lepisosteidae** | | | | | | | | | | | | | | | | |
| *Lepisosteus oculatus* | G5 | | S2 | SC | | | SC | S2S3 | | | S1 | END | | S1 | | |
| **Osteoglossiformes** | | | | | | | | | | | | | | | | |
| **Hiodontidae** | | | | | | | | | | | | | | | | |
| *Hiodon tergisus* | G5 | | | | | | THR | S2 | | END | S1 | | | S2? | | |
| **Anguilliformes** | | | | | | | | | | | | | | | | |
| **Anguillidae** | | | | | | | | | | | | | | | | |
| *Anguilla rostrata* | G5 | | | | | | | | | | | THR | | | SC | S3 |
| **Clupeiformes** | | | | | | | | | | | | | | | | |
| **Clupeidae** | | | | | | | | | | | | | | | | |
| *Alosa sapidissima* | G5 | | SX | | | | | | | | | | | | | |
| **Cypriniformes** | | | | | | | | | | | | | | | | |
| **Cyprinidae** | | | | | | | | | | | | | | | | |
| *Campostoma anomalum* | G5 | | S3 | | | | | | | | | | | | | |
| *Clinostomus elongatus* | G4 | | S3 | SC | | END | END | S1S2 | | | | | | | SC | S3? |
| *Erimystax x-punctatus* | G4 | | SX | EXP | | | | | SC | THR | S1 | | END | S1 | END | S1S2 |
| *Exoglossum laurae* | G4 | | | | | | | | | | S2 | THR | | | | |
| *Exoglossum maxillingua* | G5 | | S1S2 | | | | | | | | | | | | | |
| *Hybognathus regius* | G5 | | S2 | | | | | | | | | | | | | |
| *Luxilus chrysocephalus* | G5 | | S3 | | | | | | | | | | | | END | S1 |
| *Lythrurus umbratilis* | G5 | | | | | | | | | SC | S2 | | | S2 | THR | S3 |
| *Macrhybopsis storeriana* | G5 | | S2 | SC | | | SC | S2S3 | | END | SX | | | S1 | SC | SU |
| *Nocomis micropogon* | G5 | | | | END | | | | | | | | | | | |
| *Notropis amblops* | G5 | | | | | | EXP | | | | | | | | | |
| *Notropis anogenus* | G3 | | S2 | SC | END | | SC | S3 | SC | END | S1 | EXP | | | THR | S2S3 |
| *Notropis bifrenatus* | G5 | | S2 | SC | | | | | | | | | | S1S2 | | |
| *Notropis dorsalis* | G5 | | | | | | | | | | | THR | | S2 | | |
| *Notropis heterodon* | G5 | | | | THR | | | | | | S1 | END | | S1 | | |
| *Notropis heterolepis* | G5 | | | | END | | | | | | | END | | SX | | |
| *Notropis photogenis* | G5 | | S2S3 | SC | | | END | S1 | | | S2 | | | | | |
| *Notropis texanus* | G5 | | | | END | | EXP | S1 | | | | | | | SC | S3 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Opsopoeodus emiliae* | G5 | | S2 | SC | | | END | S1 | | | | END | | | SC | S3? |
| *Phoxinus erythrogaster* | G5 | | | | | | END | S1 | | | | | | S2S3 | | |
| | | | | | | | | | | | | | | | | |
| **Catostomidae** | | | | | | | | | | | | | | | | |
| *Catostomus catostomus* | G5 | | | | THR | | | | | | | END | END | S1 | | |
| *Erimyzon oblongus* | G5 | | | | | | END | S1S2 | | | | | | | | |
| *Erimyzon sucetta* | G5 | | S2 | SC | | | | | | THR | S1 | THR | | SX | SC | S3? |
| *Ictiobus cyprinellus* | G5 | | S? | SC | | | | | | | | | | SX | | |
| *Ictiobus niger* | G5 | | S? | SC | | | SC | S3 | SC | | | | | | THR | S2? |
| *Lagochila lacera* | GX | | | | | EXP | | | | | | EXT | | | | |
| *Minytrema melanops* | G5 | | S2 | SC | | | | | | | | | | S2 | | |
| *Moxostoma carinatum* | G4 | | S2 | SC | THR | END | THR | S1 | | | S2? | SI | | S3 | THR | S2S3 |
| *Moxostoma duquesnei* | G5 | | S2 | THR | | | | | | SC | S2 | | | | SC | S1 |
| *Moxostoma erythrurum* | G5 | | S3 | | | | | | | | | | | | | |
| *Moxostoma valenciennesi* | G3 | | S3 | | END | END | | | | | S2 | THR | | | | S2S3 |
| | | | | | | | | | | | | | | | | |
| **Siluriformes** | | | | | | | | | | | | | | | | |
| **Ictaluridae** | | | | | | | | | | | | | | | | |
| *Ameiurus melas* | G5 | | S3 | | | | | | | | | | | S1? | | |
| *Noturus insignis* | G5 | | S1 | THR | | | | | | | | | | | | |
| *Noturus miurus* | G5 | | S2 | SC | | | SC | S2S3 | | | S1 | | | S2 | | |
| *Noturus stigmosus* | G3 | | S1S2 | SC | END | | END | S1 | | | | END | THR | S1 | | |
| | | | | | | | | | | | | | | | | |
| **Salmoniformes** | | | | | | | | | | | | | | | | |
| **Esocidae** | | | | | | | | | | | | | | | | |
| *Esox americanus vermiculatus* | G5 | | S3 | | | | | | | | | | | | | |
| *Esox masquinongy* | G5 | | | | | THR | | | | | | SI | | | | |
| | | | | | | | | | | | | | | | | |
| **Salmonidae** | | | | | | | | | | | | | | | | |
| *Coregonus artedi* | G5 | | | | THR | END | THR | S3 | | | | END | | SH? | SC | S3 |
| *Coregonus clupeaformis* | G5 | | | | | | | | | | | SI | | SX | | |
| *Coregonus hoyi* | G4 | VUL | | | | | | | | | SX | | | | SC | S3? |
| *Coregonus johannae* | GX | EXT | SX | EXT | | EXP | | SX | | | | | | | | |
| *Coregonus kiyi* | G3 | VUL | S3 | SC | | SC | | S3 | SC | | SX | | | | SC | S3 |
| *Coregonus nigripinnis* | GXQ | EXT | SX | THR | | THR | EXP | SX | | | | | | | | |
| *Coregonus reighardi* | G1 | CRE | SX | THR | | THR | EXP | | | | SX | | | | | |
| *Coregonus zenithicus* | G2 | VUL | S2 | THR | | | THR | S2 | SC | | SX | | | SX | SC | S3? |
| *Prosopium coulteri* | G5 | | | | | | | | | | | | | | SC | S3? |
| *Prosopium cylindraceum* | G5 | | | | | | | | | END | S1 | | | | | |
| *Salmo salar* | G5 | | SXC | | | | | | | | | | | | | |
| *Salvelinus fontinalis* | G5 | | | | | | | | | | | THR | | | SC | S1? |
| *Salvelinus namaycush* | G5 | | | | | | | | | | | SI | | SH | | |
| *Thymallus arcticus* | G5 | | | | | | | SX | EXP | | | | | | | |
| | | | | | | | | | | | | | | | | |
| **Percopsiformes** | | | | | | | | | | | | | | | | |
| **Aphredoderidae** | | | | | | | | | | | | | | | | |
| *Aphredoderus sayanus* | G5 | | | | | | | | SC | | S1 | END | | SX | SC | S3 |
| | | | | | | | | | | | | | | | | |
| **Gadiformes** | | | | | | | | | | | | | | | | |
| **Gadidae** | | | | | | | | | | | | | | | | |
| *Lota lota* | G5 | | | | | | | | | | | SI | THR | S1S2 | | |
| | | | | | | | | | | | | | | | | |
| **Atheriniformes** | | | | | | | | | | | | | | | | |
| **Fundulidae** | | | | | | | | | | | | | | | | |
| *Fundulus diaphanus* | G5 | | | | THR | | | | | | | END | | | SC | S3? |
| *Fundulus dispar* | G4 | | | | | | | | | | | | | | END | S2 |
| *Fundulus notatus* | G5 | | S2 | SC | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scorpaeniformes** | | | | | | | | | | | | | | | | |
| **Cottidae** | | | | | | | | | | | | | | | | |
| *Cottus ricei* | G5 | | | | | | SC | S3 | | END | SX | SI | | | | |
| *Myoxocephalus thompsoni* | G5 | | | THR | | | | | | END | SX | | | SU | | |
| | | | | | | | | | | | | | | | | |
| **Perciformes** | | | | | | | | | | | | | | | | |
| **Centrarchidae** | | | | | | | | | | | | | | | | |
| *Lepomis gulosus* | G5 | | S1 | SC | | | | | | | | | | S1S2 | | |
| *Lepomis humilis* | G5 | | S3 | SC | | | | | | | | | | | | |
| *Lepomis megalotis* | G5 | | S3 | | | | | | | THR | S1 | | | S1 | THR | S2 |
| *Pomoxis annularis* | G5 | | S3 | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| **Percidae** | | | | | | | | | | | | | | | | |
| *Ammocrypta pellucida* | G3 | VUL | S2 | THR | | END | THR | S1S2 | | THR | S1 | SI | END | S1 | | |
| *Etheostoma blennioides* | G5 | | | SC | | | | | | | | | | | | |
| *Etheostoma chlorosomum* | G5 | | | | | | | | | | | | | | END | S1 |
| *Etheostoma exile* | G5 | | | | END | | | | | | S2 | SI | | S1 | | |
| *Etheostoma microperca* | G5 | | | | | | | | SC | | | SI | | | SC | S3 |
| *Percina copelandi* | G4 | | S2 | THR | | | END | S1S2 | | | S2 | THR | THR | S1S2 | SC | |
| *Percina shumardi* | G5 | | S3 | | | | END | S1 | | | | THR | | | | |
| *Stizostedion canadense* | G5 | | | | | | THR | S1 | | | S1 | | | | | |
| *Stizostedion vitreum glaucum* | GX | | SX | EXT | | | EXP | SX | | | | EXT | | SX | | |

` - Committee on the Status of Endangered Wildlife in Canada
`` - World Conservation Union
``` - Global Conservation Ranks (as given by The Nature Conservancy)

**Status/Ranking Codes**
END = endangered
EXP = extripated
EXT = extinct
SC = special concern
SI = special interest
THR = threatened
VUL = vulnerable

*Natural Heritage Information Centre Rankings/State Codes*
S1 = extremely rare; 5 or fewer occurrences in province or few remaining individuals
S2 = very rare; usually between 5 and 20 occurrences in province
S3 = rare to uncommon; usually between 20 and 100 occurrences in province
SH = historically present, but no documented occurrences for extended period of time, but still believed to be extant
SX = apparently extripated from province
SXC = naturally extripated but exists in province as cultivated species (C = cultivated or in captivity)
S?/SU = unranked; species thought to be rare but data is insufficient
? = ranking questionable

*Additional IUCN Codes*
CRE = critically endangered
LR = lower risk; may easily become threatened

**Global Conservation Status Ranks**
G1 = critically imperiled
G2 = imperiled
G3 = vulnerable
G4 = apparently secure
G5 = secure
GX = presumed extinct
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GH = possibly extinct
Q = questionable taxonomy that may reduce conservation priority

**References**


Illinois Department of Natural Resources. *Illinois' Endangered and Threatened Species List*.
dnr.state.il.us/espb/datelist.htm. Site visited 30 June, 2000.

Indiana Department of Natural Resources: Division of Fish and Wildlife. *Indiana's Endangered Wildlife - Fish*.
www.state.in.us/dnr/fishwild/nongame/fish.htm. Site visited 29 June, 2000.

Michigan Department of Natural Resources. *Michigan's List of Endangered Species*.
www.dnr.state.mi.us. Site visited 21 June, 2000.

Michigan Natural Features Inventory. 15 November, 2000. *Michigan's Special Animals*. www.dnr.state.mi.us/pdfs/wildlife/TE_animals.pdf.
Site visited 12 February, 2001.

Minnesota Department of Natural Resources. *Minnesota DNR - Endangered, Threatened and Special Concern Fish*.
www.dnr.state.mn.us/fish_and_wildlife/endangered_species/endfish.html. Site visited 29 June, 2000.

National Heritage Information Centre. 4 April, 2000. *NHIC List of Ontario Fish*.
www.mnr.gov.on.ca/MNR/nhic/queries/listout.cfm?el=af. Site visited 21 June, 2000.

Nature Conservancy, The. *Freshwater Fishes of the U.S./Canada*. www.tnc.org/frames/index.html?/html/list.html.
Site visited 28 August, 2000.

New York Natural Heritage Program. 19 July 2000. *Animal Species Actively Inventoried - Biological and Conservation Data System*. www.dec.state.ny.us/website/dfwmr/heritage/AnimList.pdf. Site visited 13 February, 2001

New York State Department of Environmental Conservtion. 29 December, 1999. *List of Endangered, Threatened and Special Concern Fish & Wildlife Species of New York State*. www.dec.state.ny.us/website/dfwmr/wildlife/endspec/etsclist.html.
Site visited 29 June, 2000.

Ohio Department of Natural Resources. *Ohio's Endangered/Extripated/Extinct/Special Interest/Threatened Species List*.
www.dnr.state.oh.us/odnr/wildlife/publications/endangered/endng1.html. Site visited 14 June, 2000.

Pennsylvania Department of Conservation and Natural Resources. *Endangered and Threatened Species of Pennsylvania*.
www.dcnr.state.pa.us/wrcf/pubindex.htm. Site visited 29 June, 2000.

Pennsylvania Natural Diversity Inventory (PNDI). 3 May, 2000. *Pennsylvania Natural Diversity Inventory Index - Vertebrates*.
www.dcnr.state.pa.us/forestry/pndi/fullvertebrates.asp. Site visited 8 February, 2001.

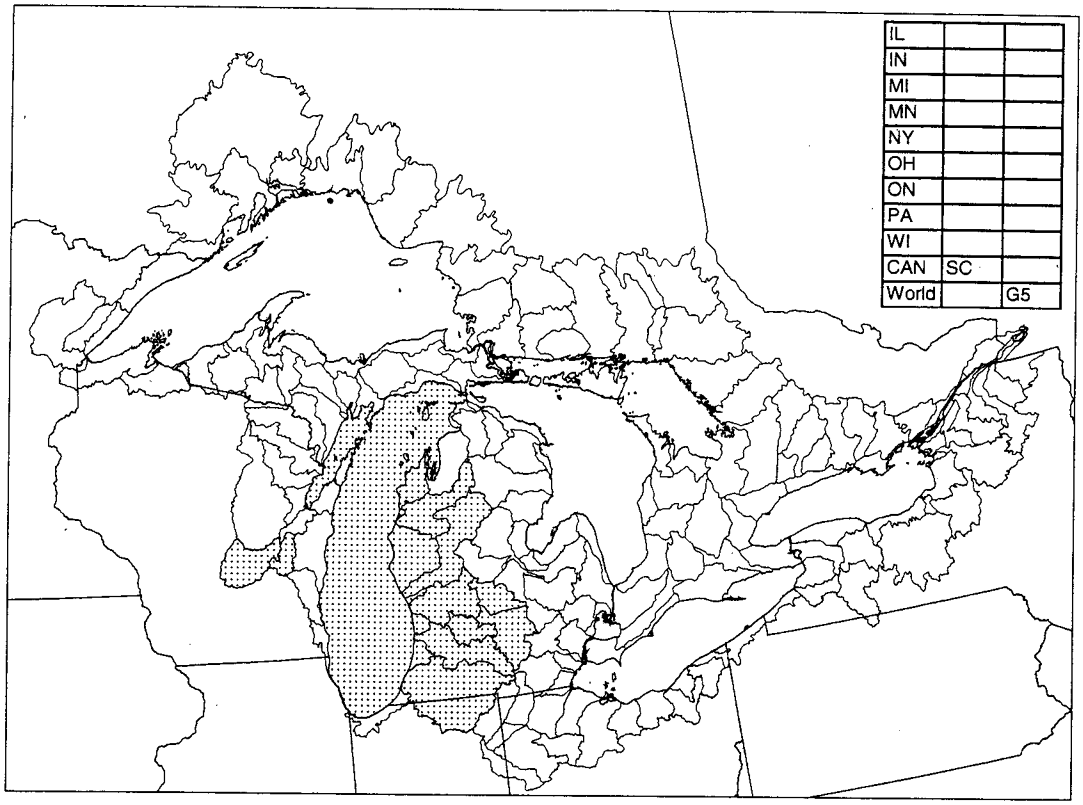
Royal Ontarion Museum. *Ontario's Biodiversity: Ontario's Fish at Risk*.
www.rom.on.ca/cgi-bin/cbcb/risk. Site visited 14 June, 2000.

United States Fish and Wildlife Service. *U.S. Listed Vertebrate Animal Species Report by Taxonomic Group*.
ecos.fws.gov/webpage/webpage_vip_listed.html. Site visited 21 June, 2000.

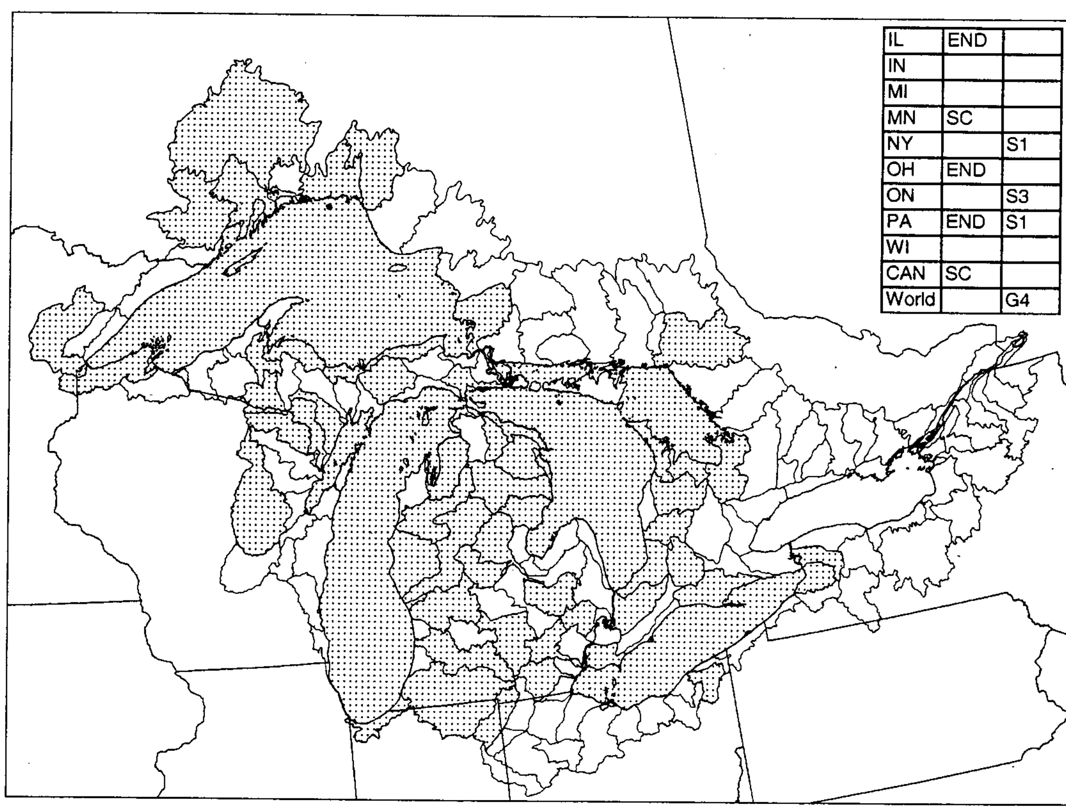
Wisconsin Department of Natural Resources. 28 June, 1999. *The Working List: Rare Fish*.
www.dnr.state.wi.us/org/land/er/workinglists/taxalists/list5.htm. Site visited 29 June, 2000.

World Conservation Monitoring Centre. 4 February, 2000. *IUCN Red List of Threatened Animals (1996)*.
www.wcmc.org.UK/species/animals/animal_redlist.html. Site visited 13 July, 2000.

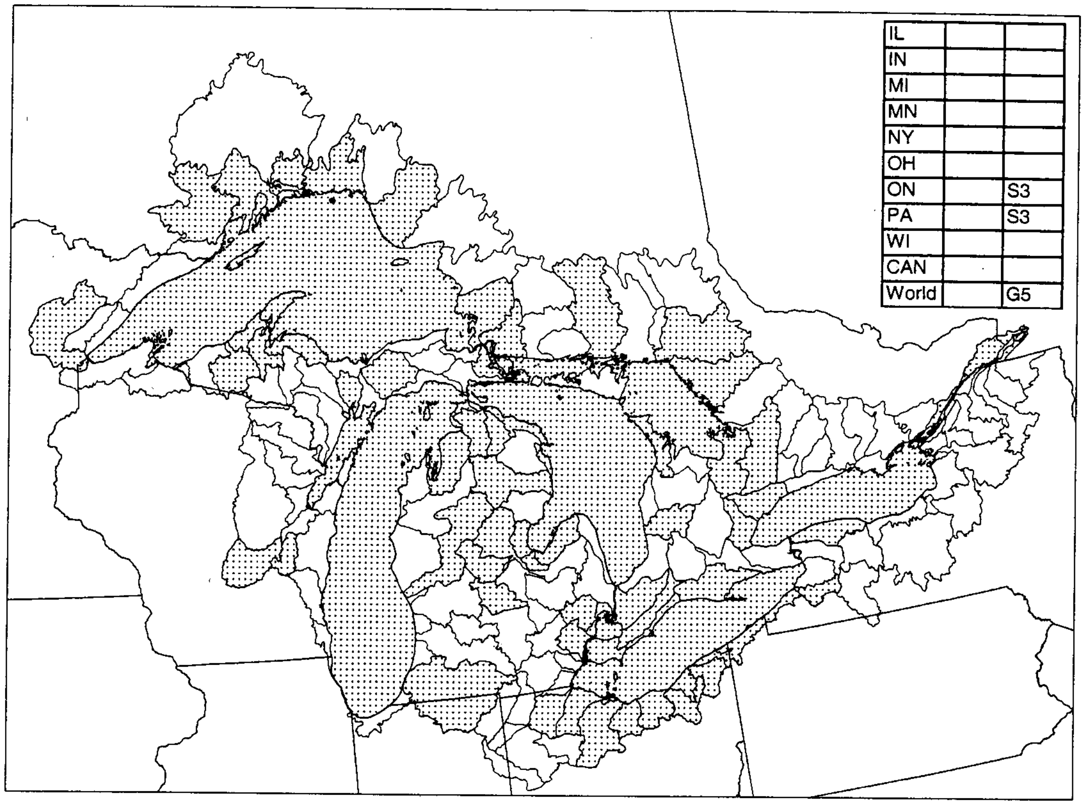
Appendix C. The maps on the following pages display the presence or absence of each fish species in the Great Lakes basin. There are several codes which describe a species condition within each watershed and lake; no fill – does not occur, stipple – occurrs naturally, crosshaching – extirpated. If two stipple patterns used; heavy stipple – native, light stipple – introduced.



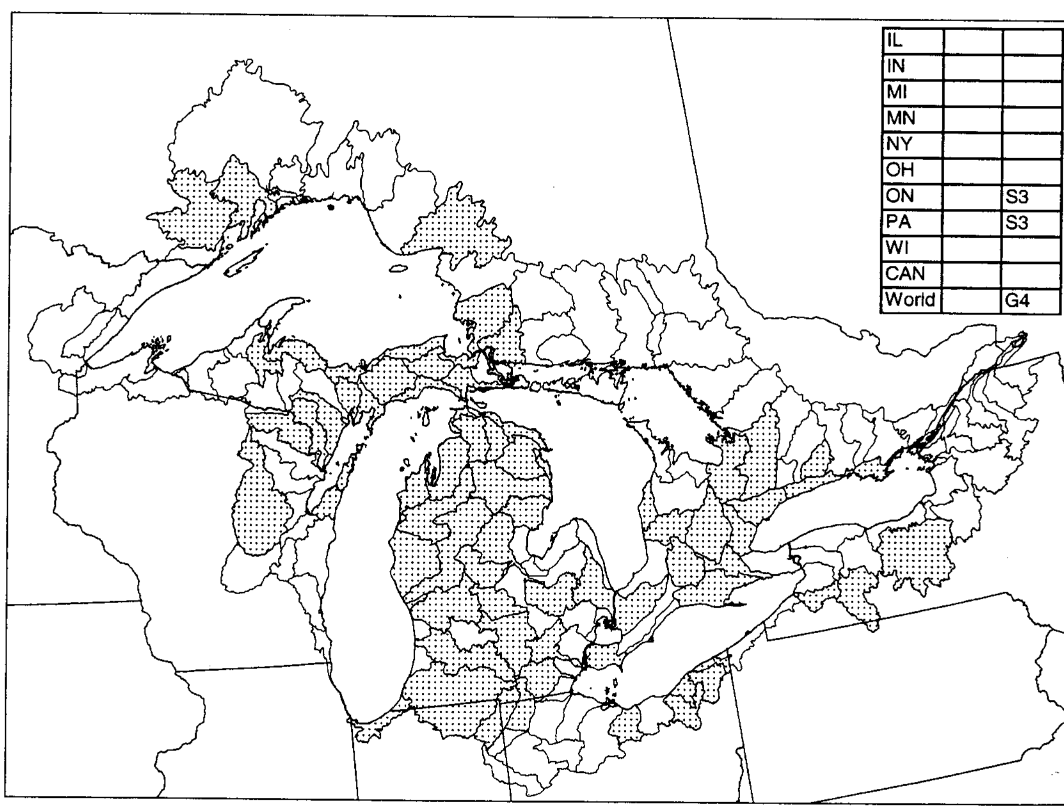

Distribution and conservation status of the chestnut lamprey, *Ichthyomyzon castaneus*, in the Great Lakes basin.



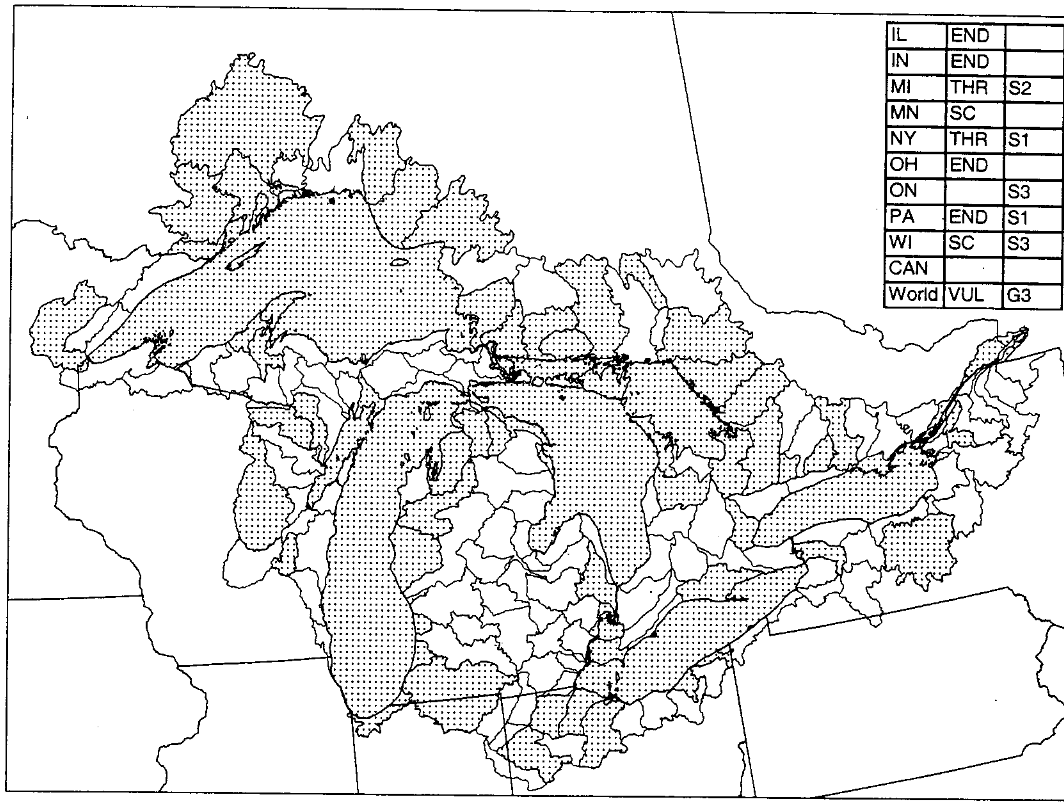

Distribution and conservation status of the northern brook lamprey, *Ichthyomyzon fossor*, in the Great Lakes basin.



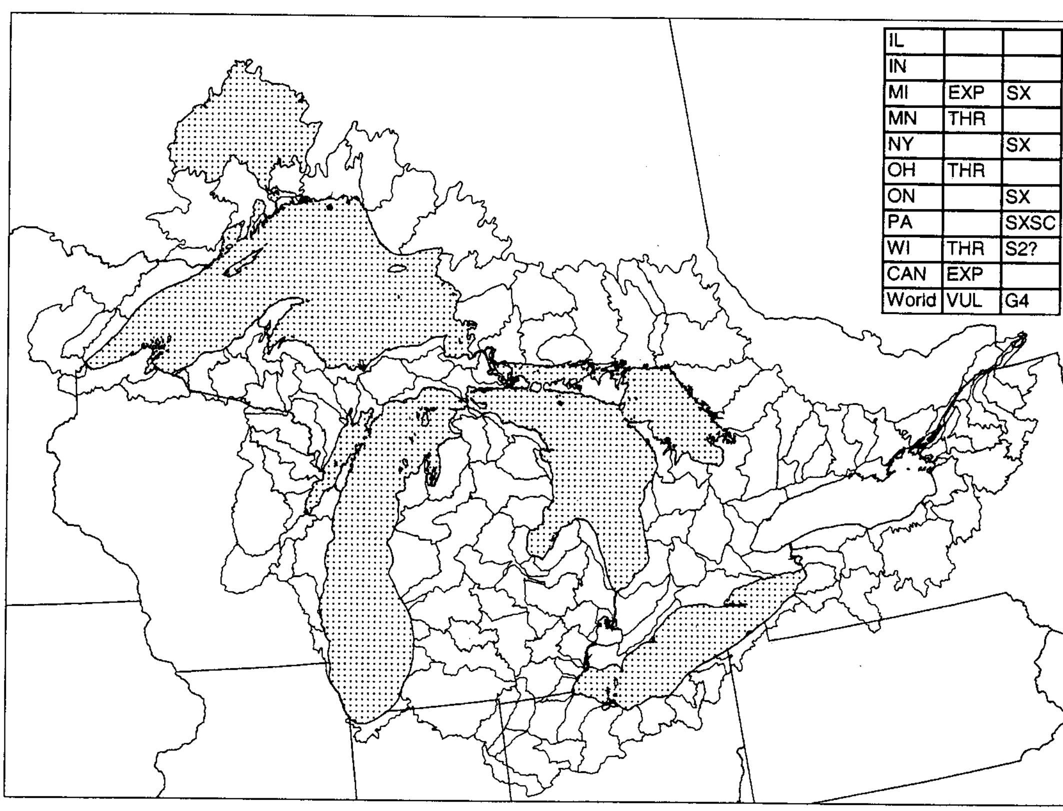
Distribution and conservation status of the silver lamprey, *Ichthyomyzon unicuspis*, in the Great Lakes basin.



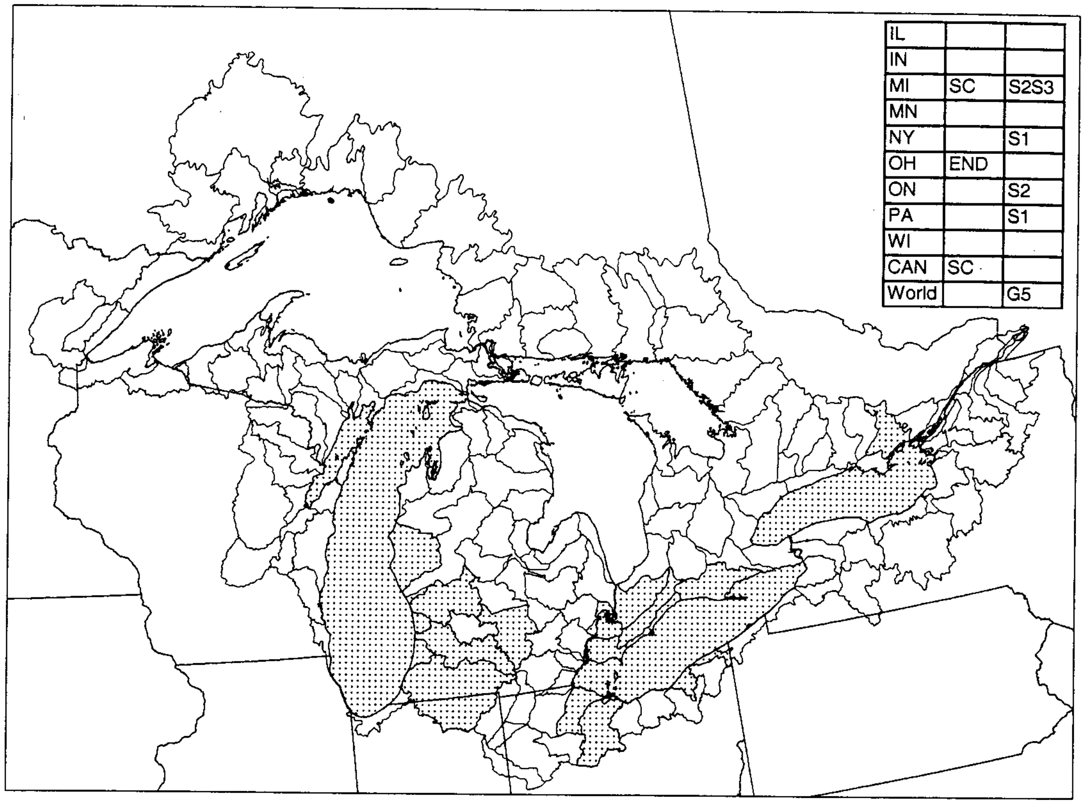
Distribution and conservation status of the American brook lamprey, *Lampetra appendix*, in the Great Lakes basin.



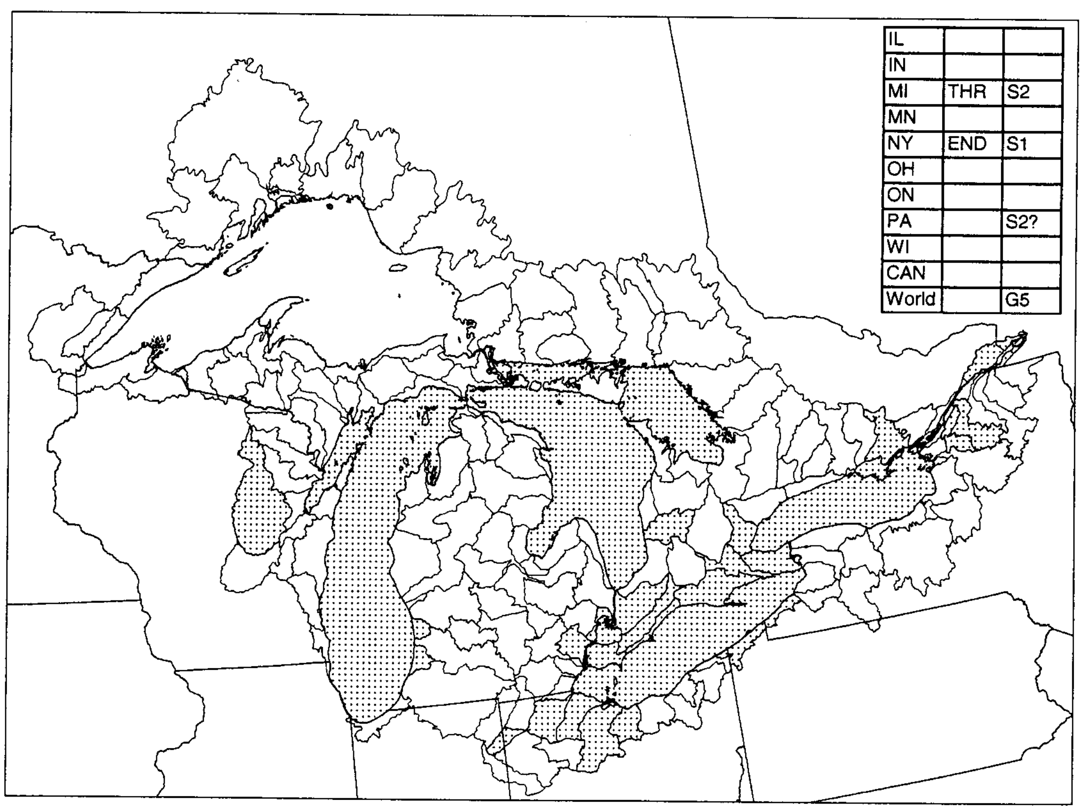

Distribution and conservation status of the lake sturgeon, *Acipenser fulvescens*, in the Great Lakes basin.



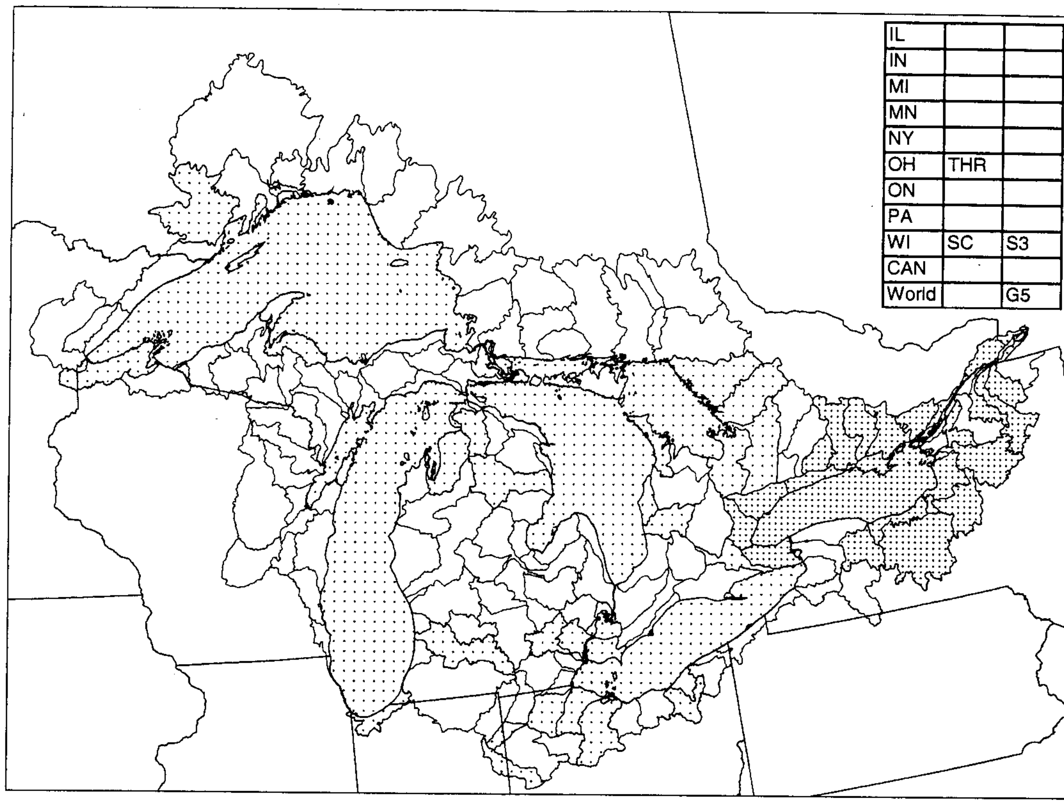

Distribution and conservation status of the paddlefish, *Polyodon spathula*, in the Great Lakes basin.



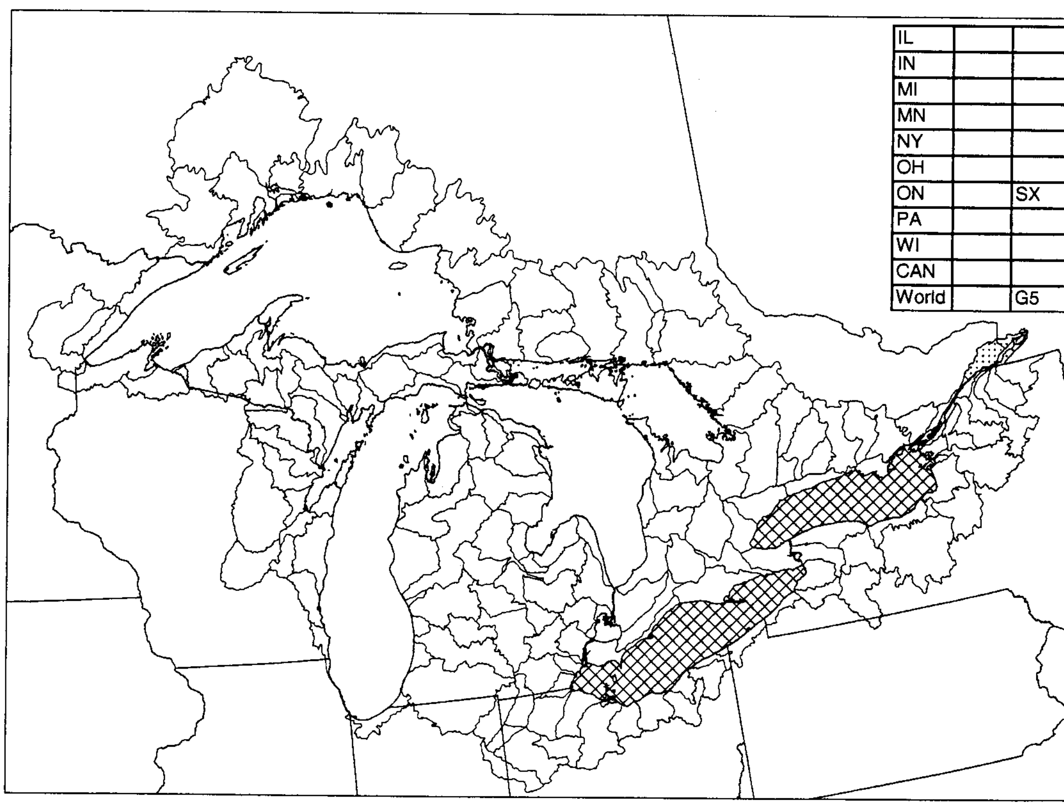

Distribution and conservation status of the spotted gar, *Lepisosteus oculatus*, in the Great Lakes basin.



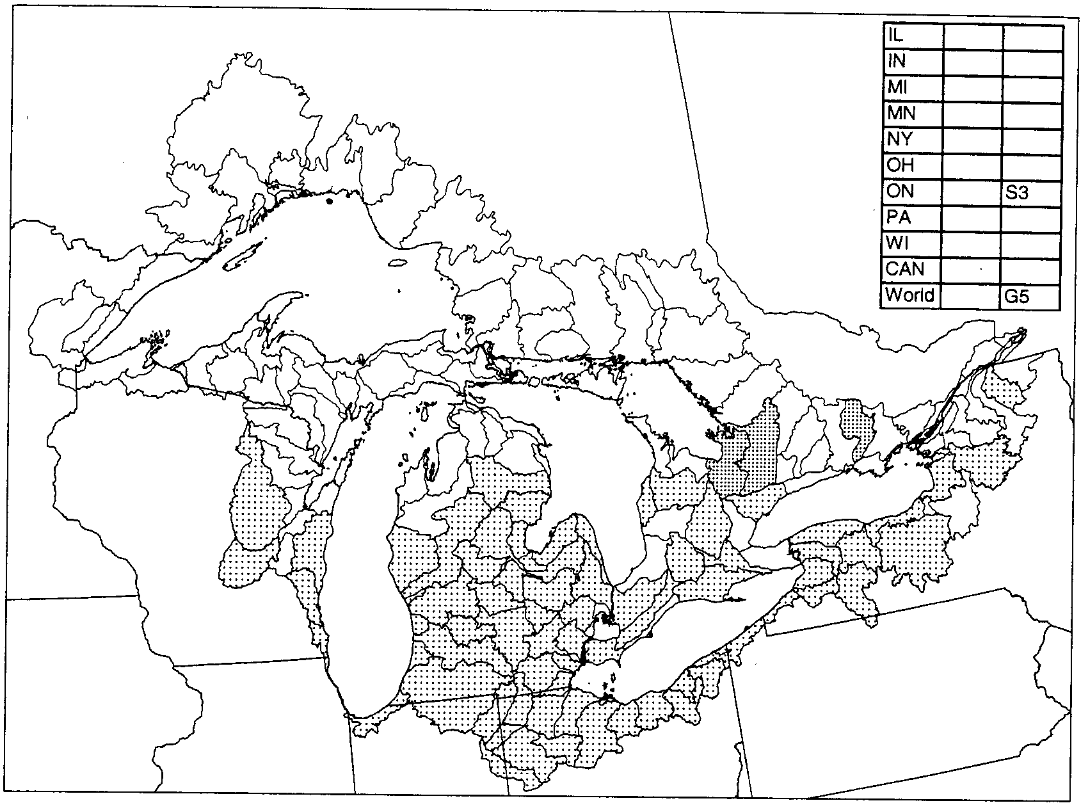

Distribution and conservation status of the mooneye, *Hiodon tergisus*, in the Great Lakes basin.



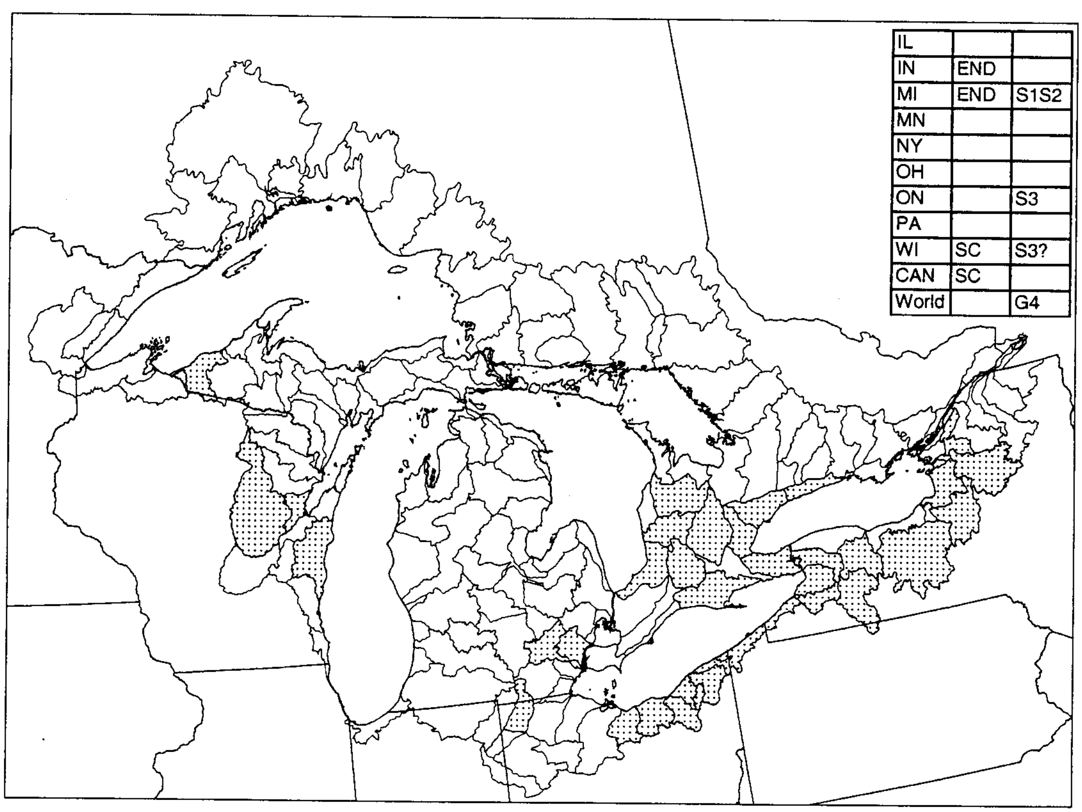

Distribution and conservation status of the American eel, *Anguilla rostrata*, in the Great Lakes basin. Heavy stipple- native; light stipple- introduced.



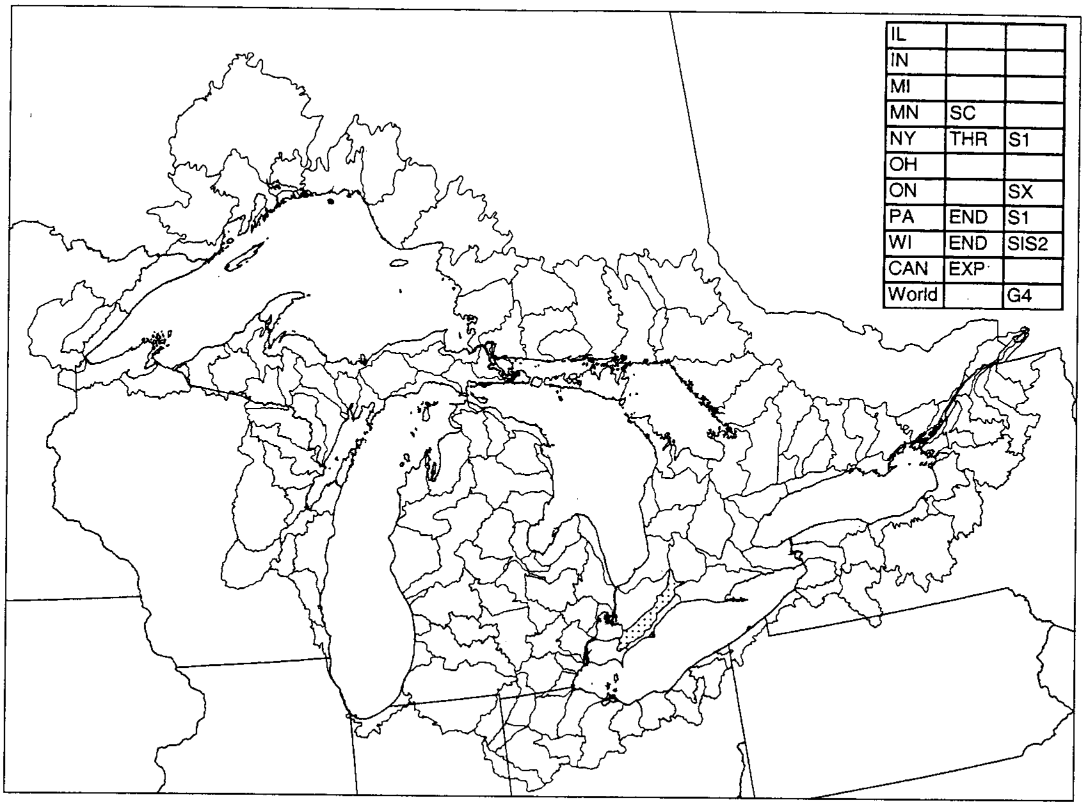

Distribution and conservation status of the American shad, *Alosa sapidissima*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.



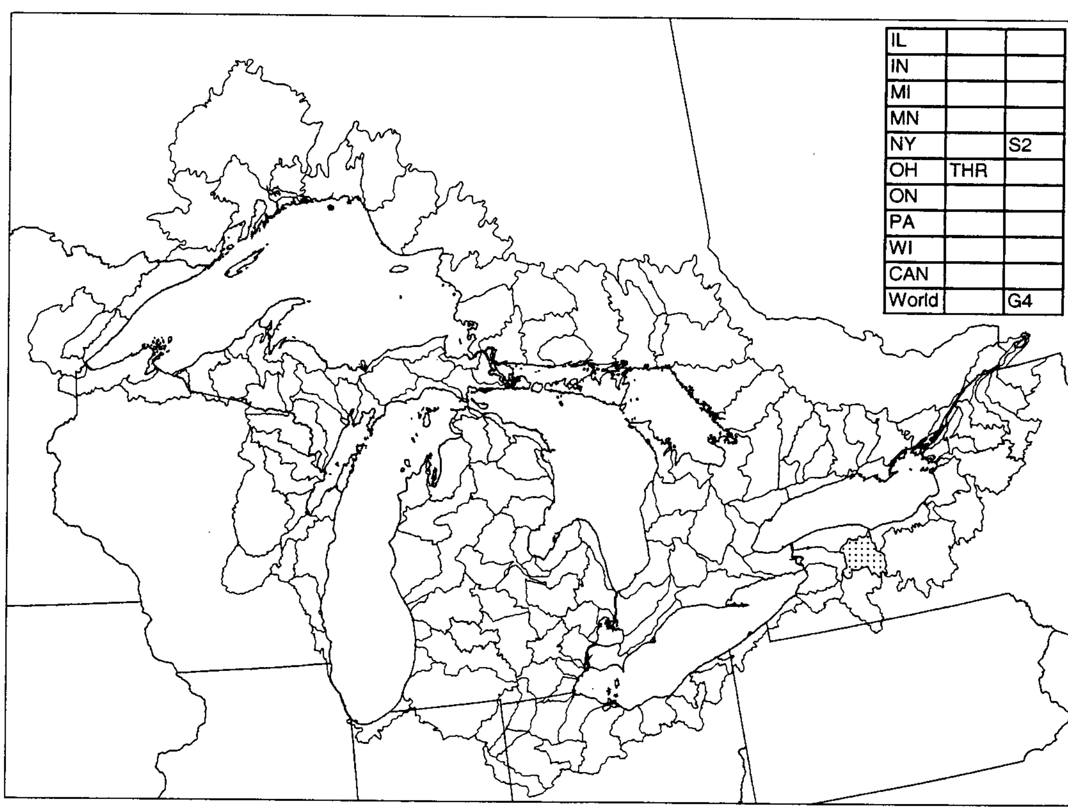

Distribution and conservation status of the central stoneroller, *Campostoma anomalum*, in the Great Lakes basin. Heavy stipple- native; light stipple- introduced.



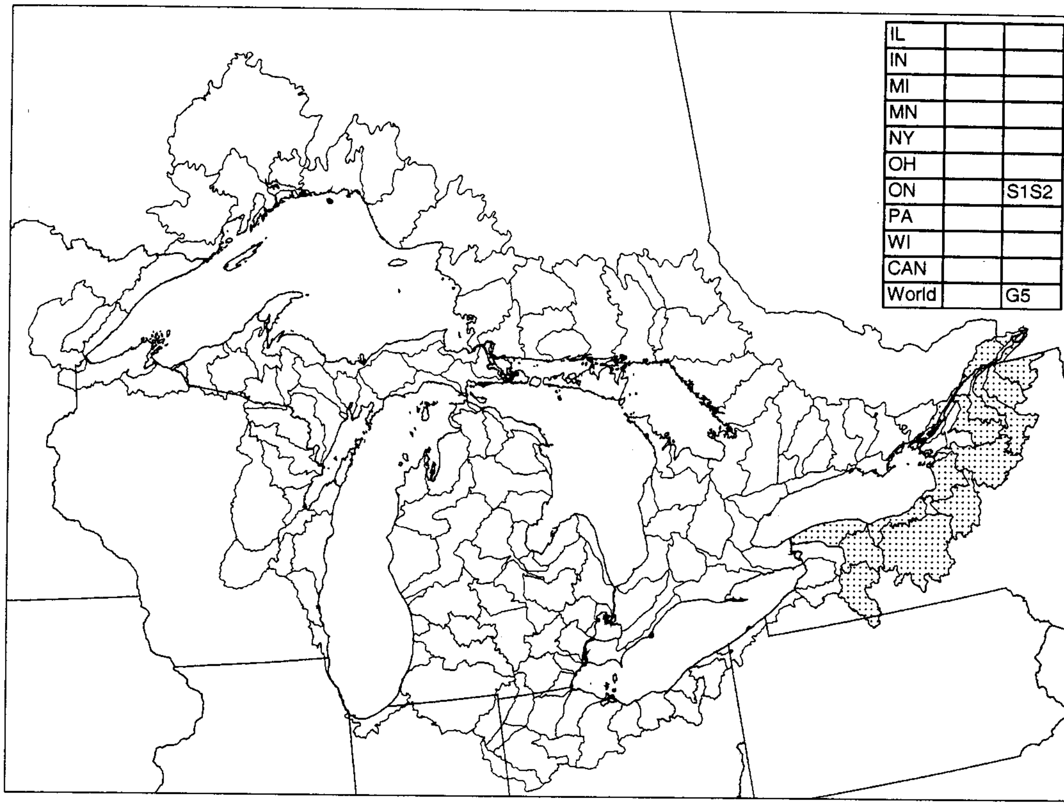

Distribution and conservation status of the redside dace, *Clinostomus elongatus*, in the Great Lakes basin.



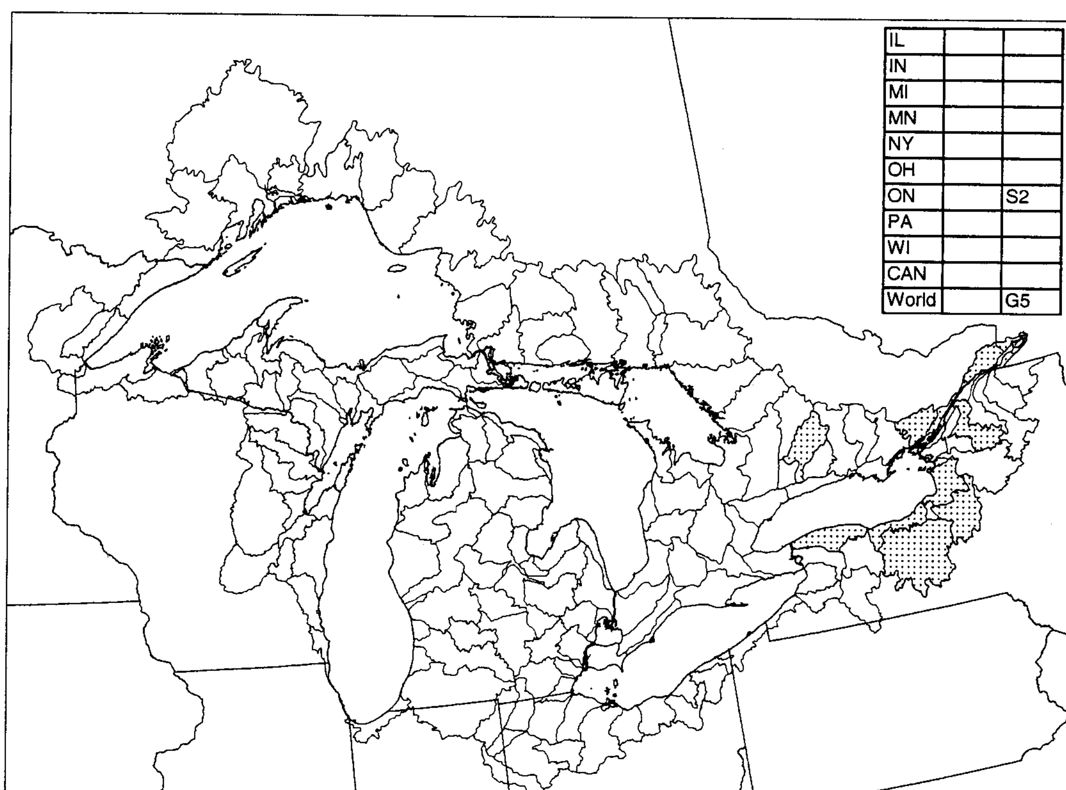

Distribution and conservation status of the gravel chub, *Erimystax x-punctatus*, in the Great Lakes basin.



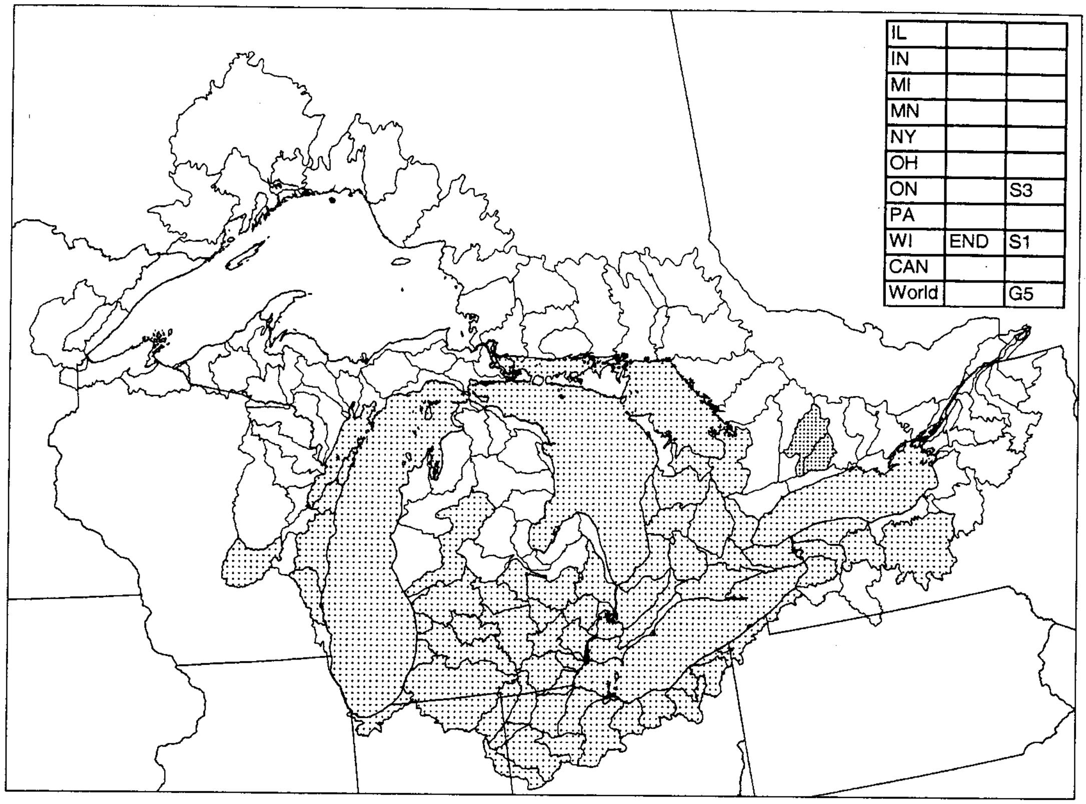

Distribution and conservation status of the tonguetied minnow, *Exoglossum laurae*, in the Great Lakes basin.



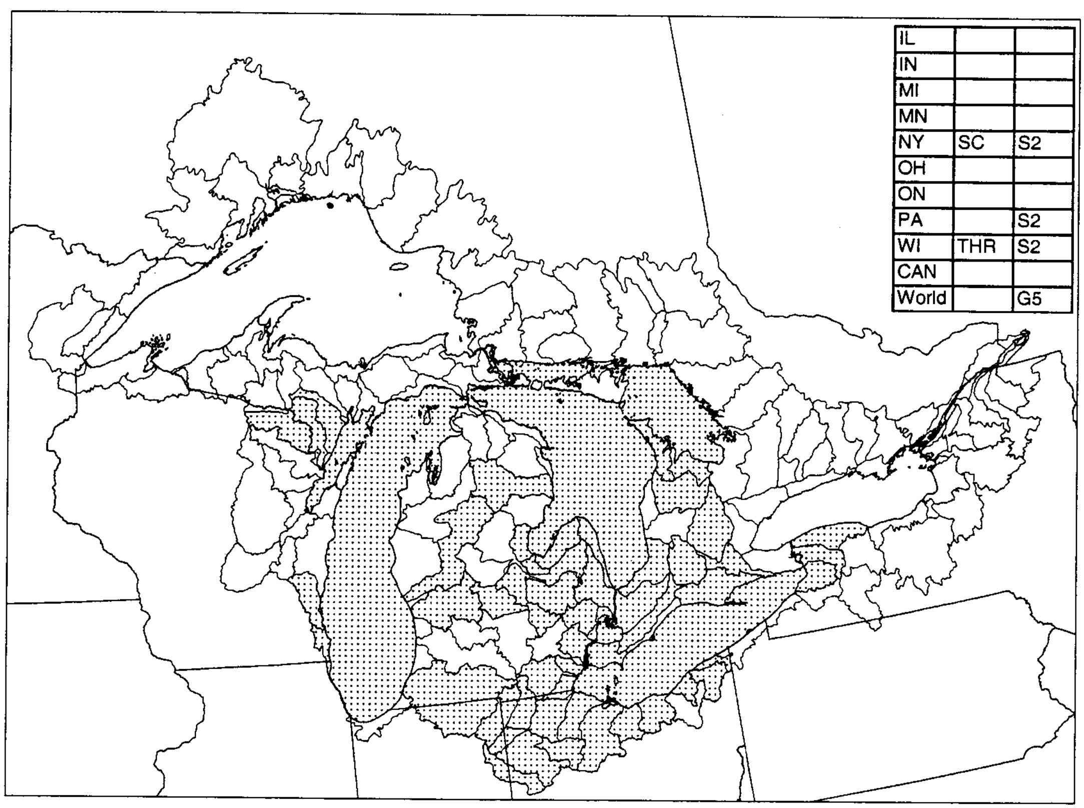

Distribution and conservation status of the cutlips minnow, *Exoglossum maxillingua*, in the Great Lakes basin.



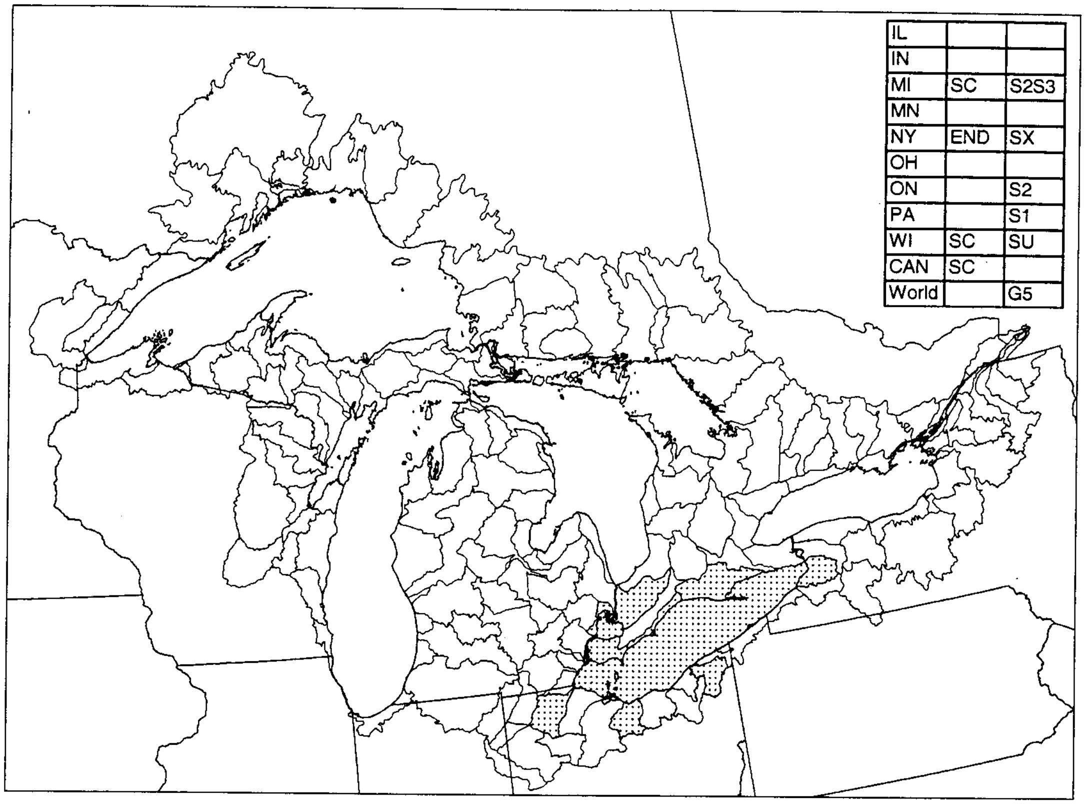

Distribution and conservation status of the eastern silvery minnow, *Hybognathus regius*, in the Great Lakes basin.



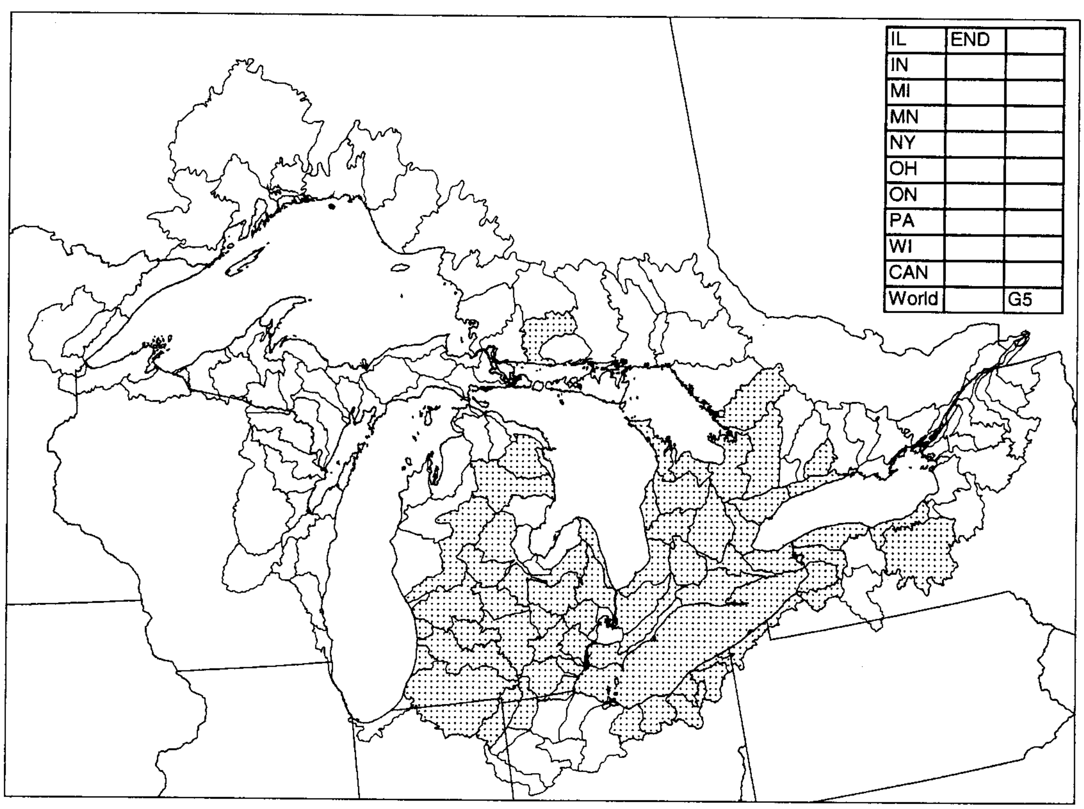

Distribution and conservation status of the striped shiner, *Luxilis chrysocephalus*, in the Great Lakes basin. Heavy stipple- native; light stipple- introduced.



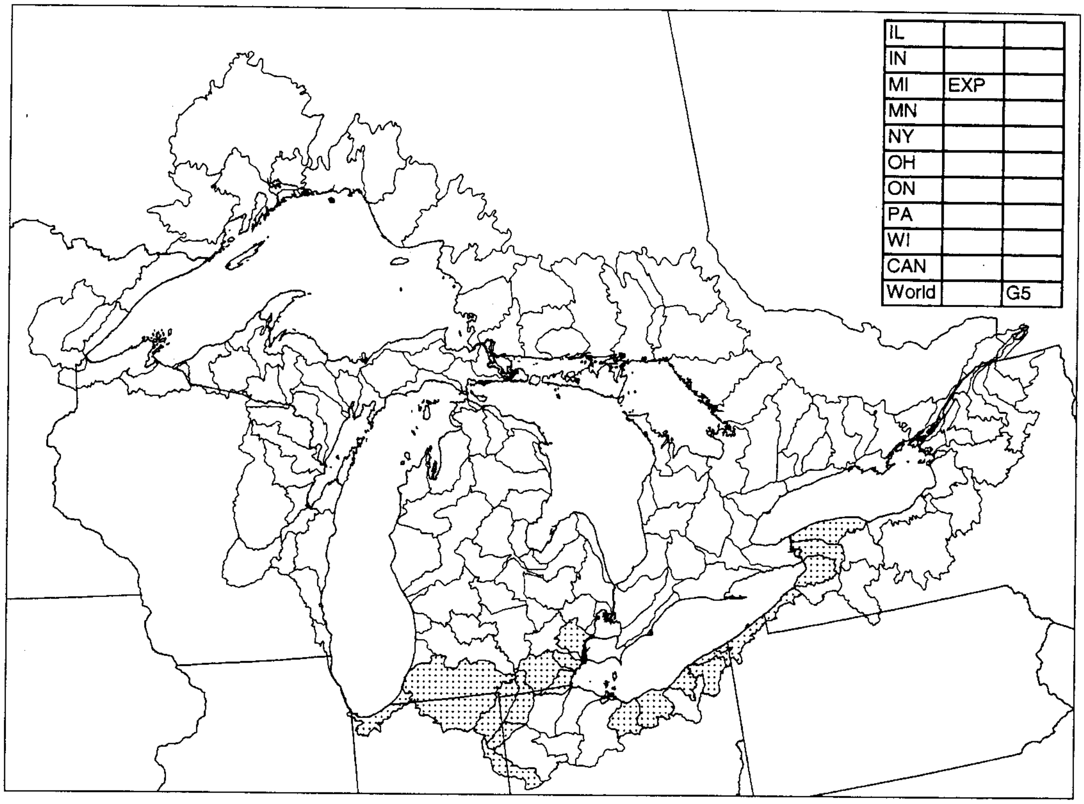

Distribution and conservation status of the redfin shiner, *Lythrurus umbratilis*, in the Great Lakes basin.



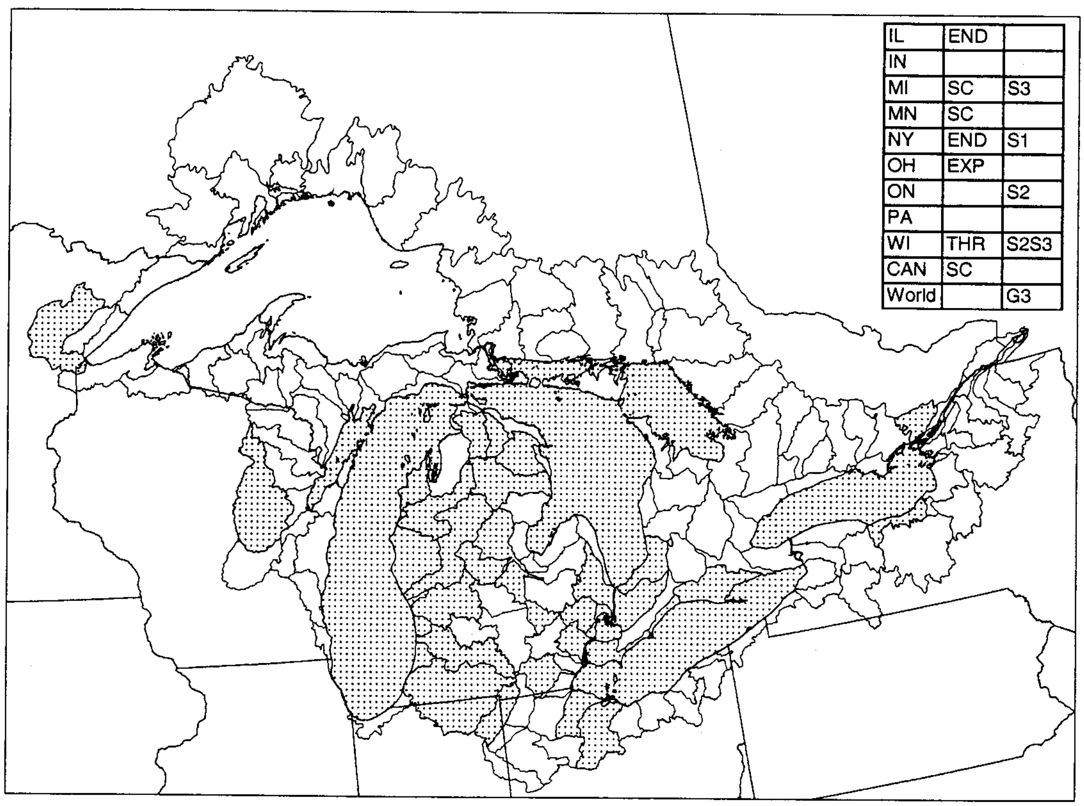

Distribution and conservation status of the silver chub, *Machrybopsis storeriana*, in the Great Lakes basin.



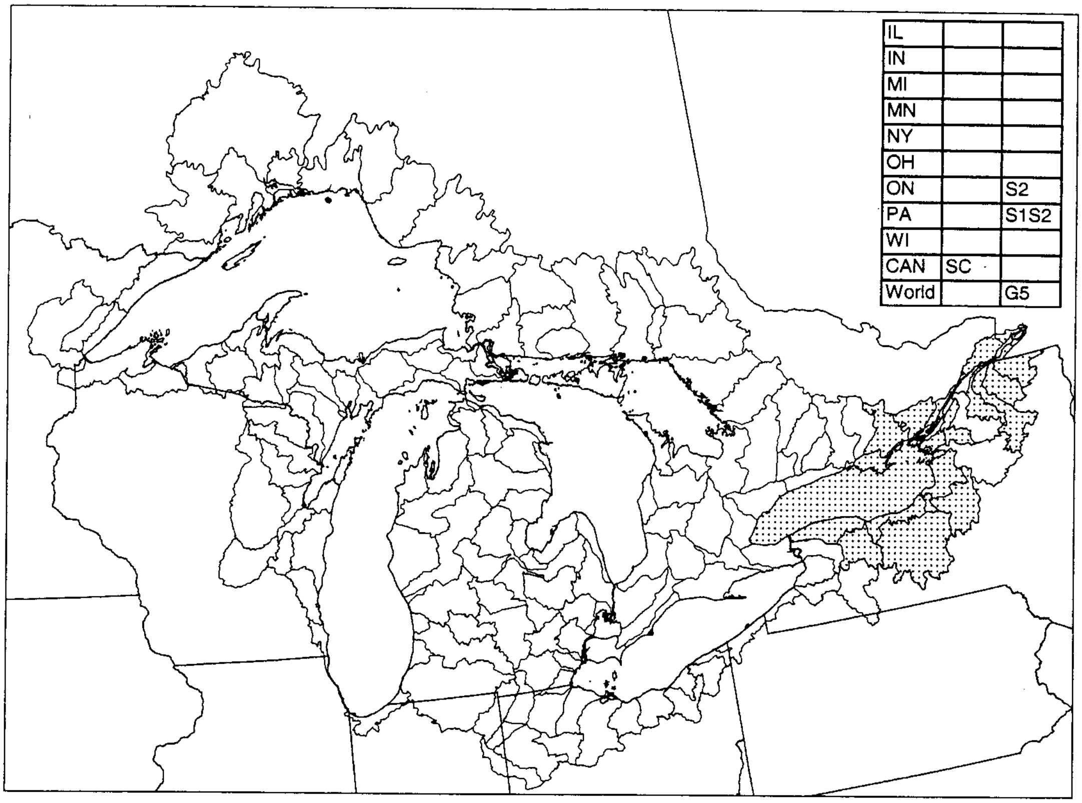

Distribution and conservation status of the river chub, *Nocomis micropogon*, in the Great Lakes basin.



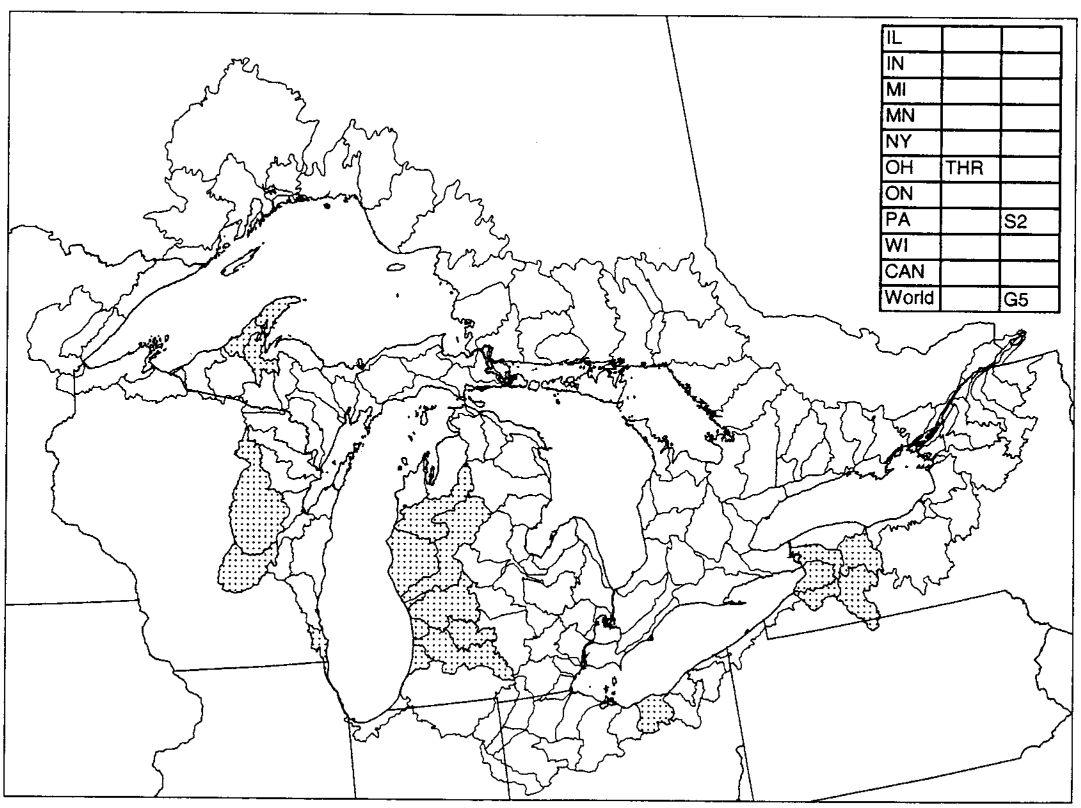

Distribution and conservation status of the bigeye chub, *Notropis amblops*, in the Great Lakes basin.



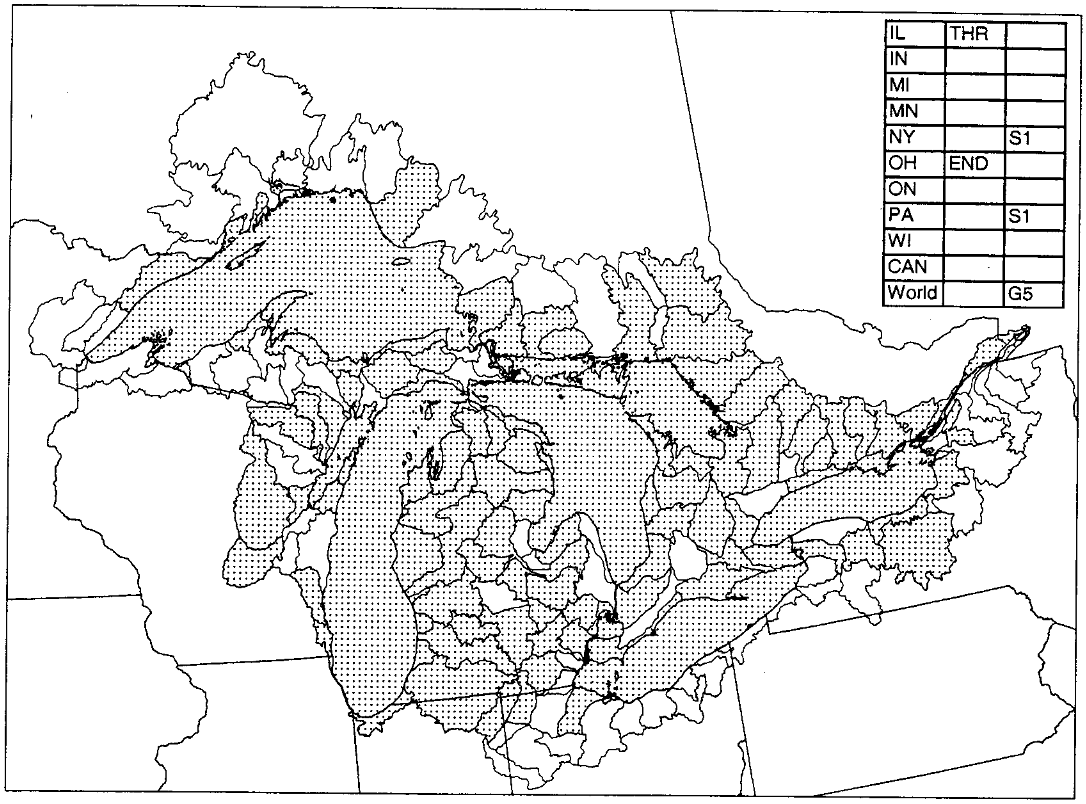

Distribution and conservation status of the pugnose shiner, *Notropis anogenus*, in the Great Lakes basin.



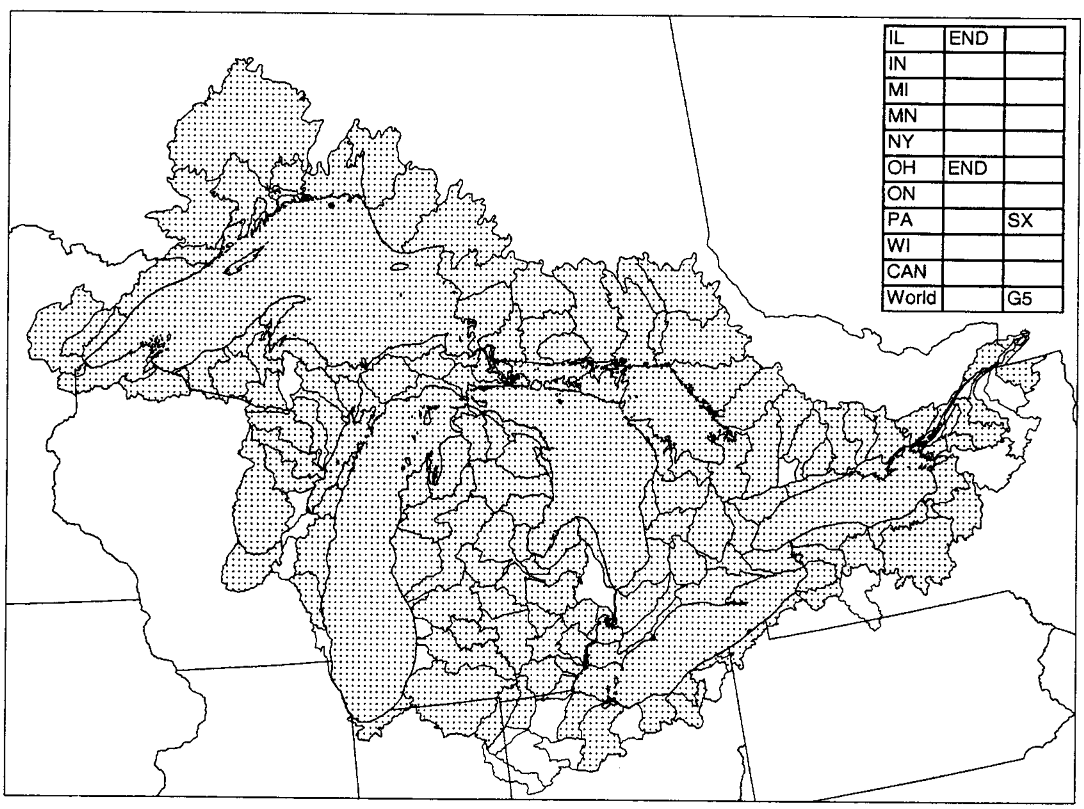

Distribution and conservation status of the bridle shiner, *Notropis bifrenatus*, in the Great Lakes basin.



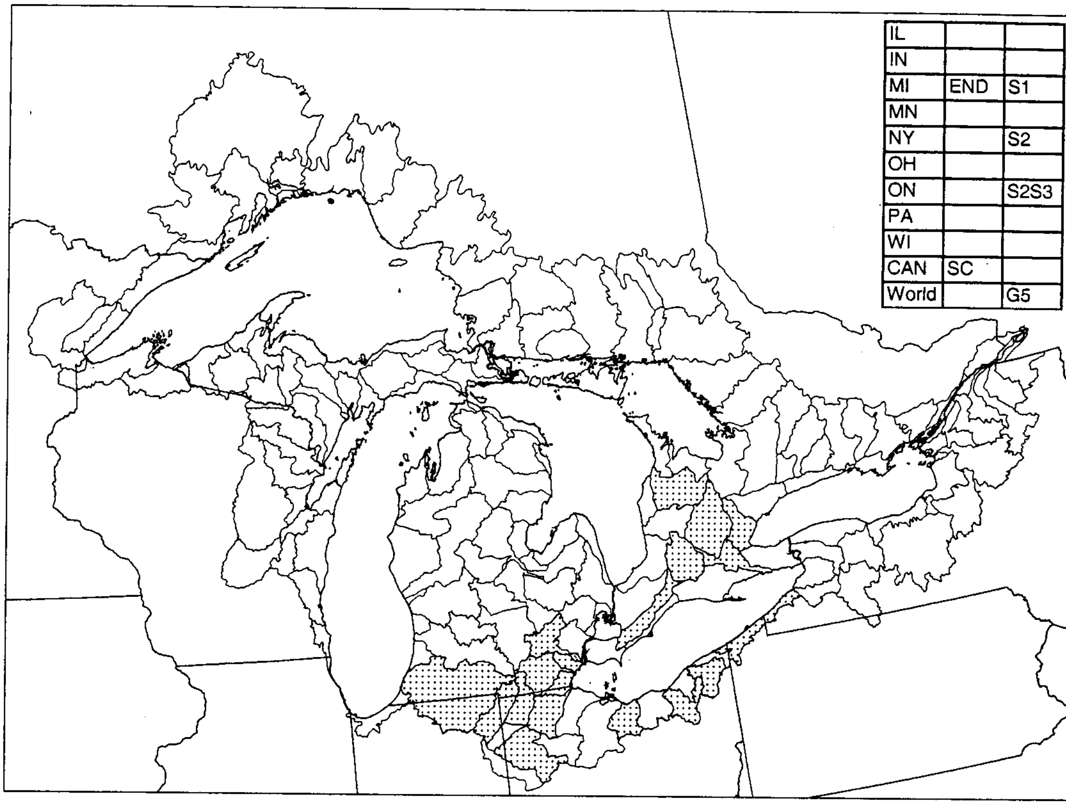

Distribution and conservation status of the bigmouth shiner, *Notropis dorsalis*, in the Great Lakes basin.



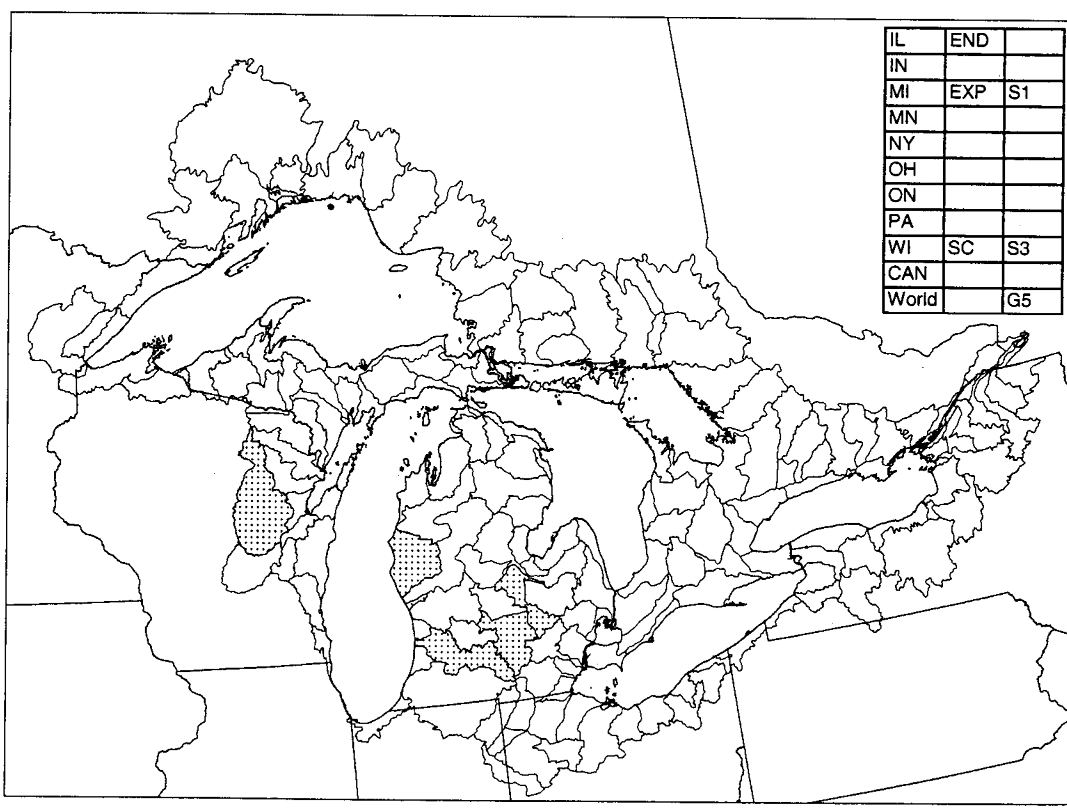
Distribution and conservation status of the blackchin shiner, *Notropis heterodon*, in the Great Lakes basin.



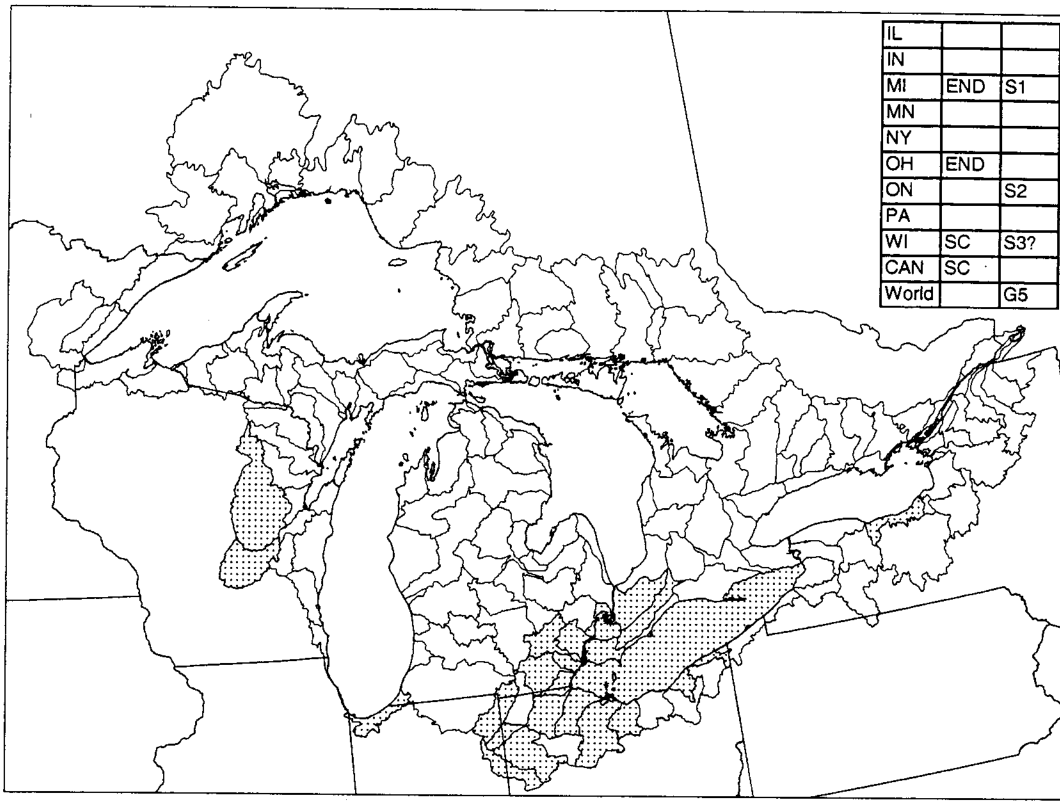
Distribution and conservation status of the blacknose shiner, *Notropis heterolepis*, in the Great Lakes basin.



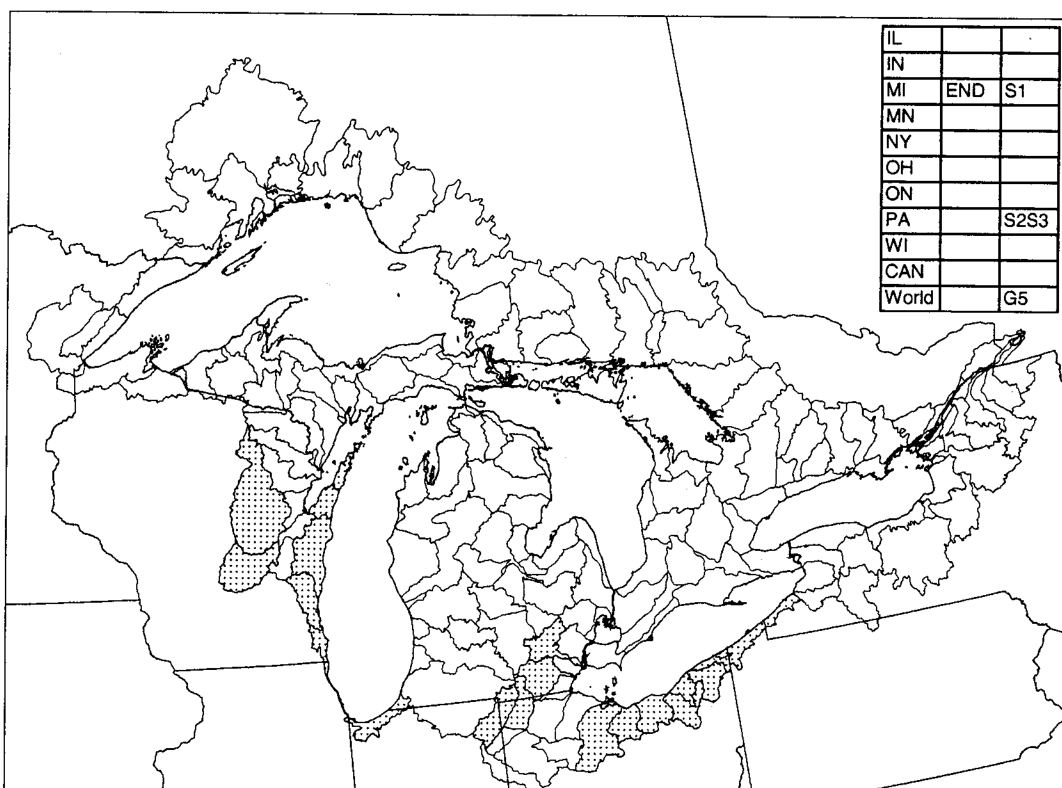

Distribution and conservation status of the silver shiner, *Notropis photogenis*, in the Great Lakes basin.



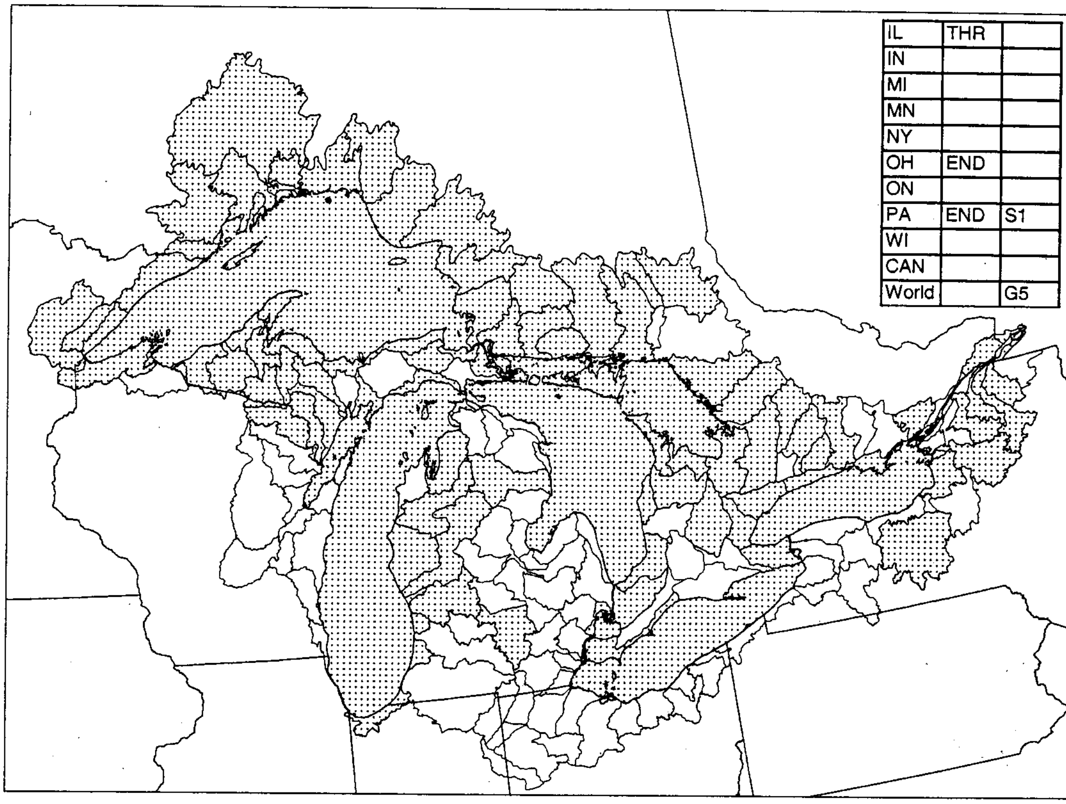

Distribution and conservation status of the weed shiner, *Notropis texanus*, in the Great Lakes basin.



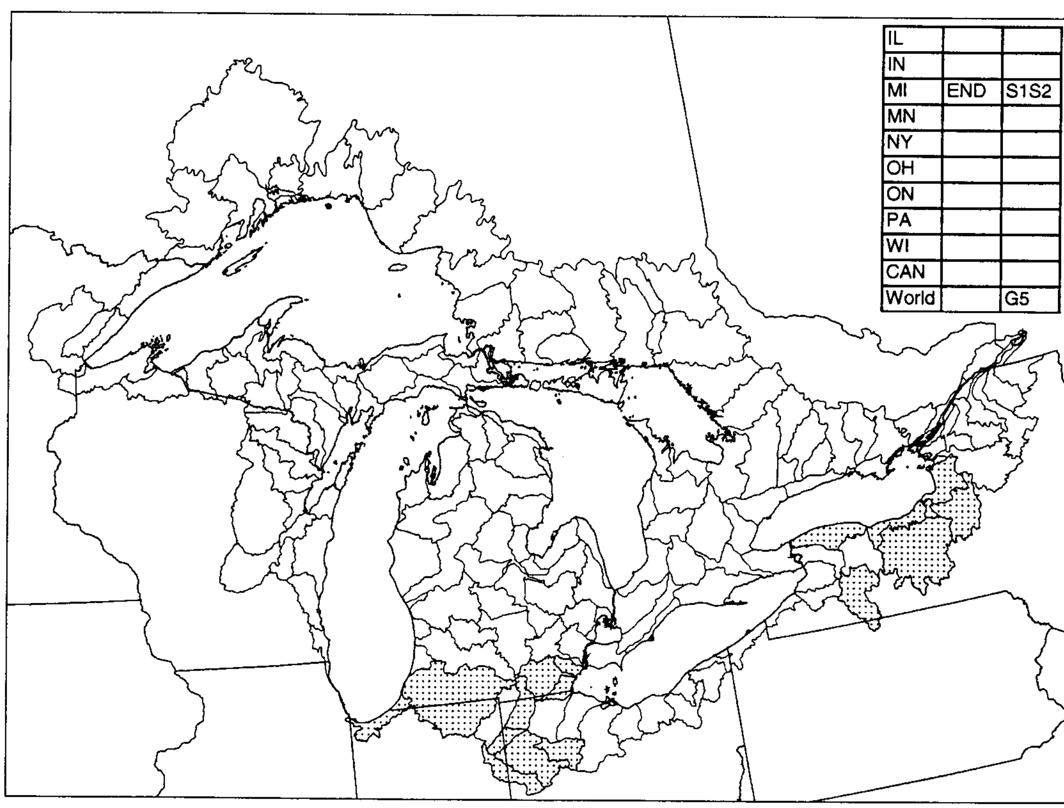

Distribution and conservation status of the pugnose minnow, *Opsopoeodus emiliae*, in the Great Lakes basin.



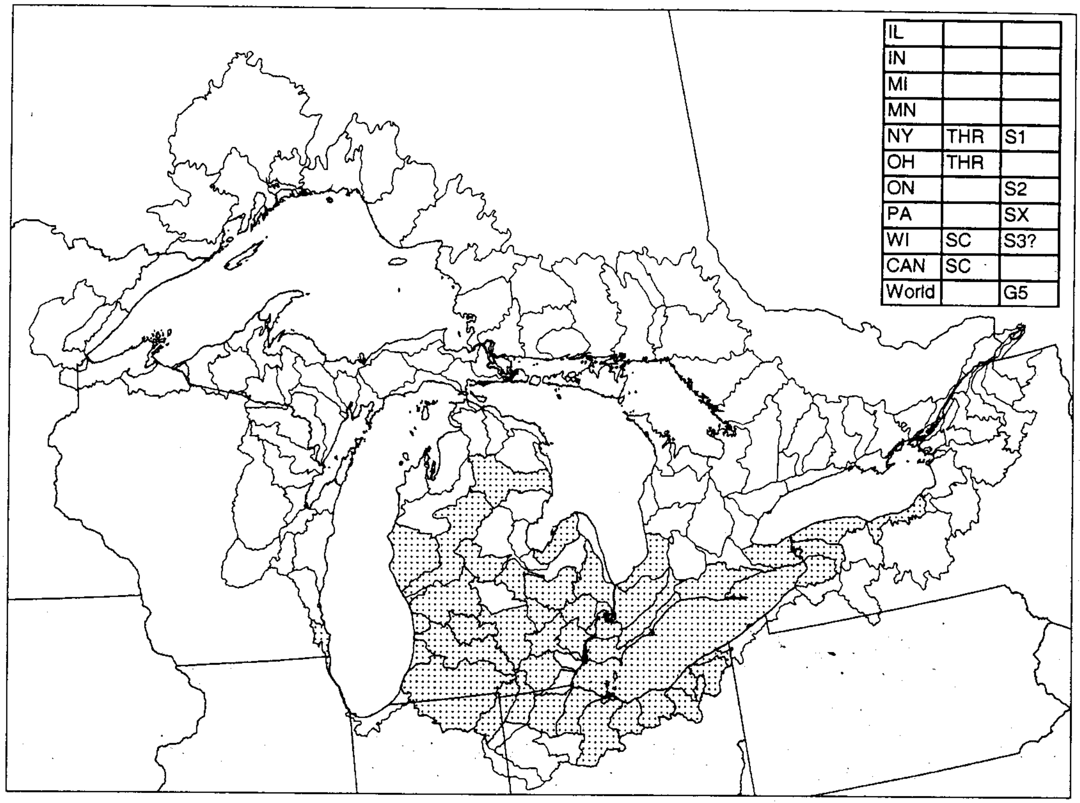

Distribution and conservation status of the southern redbelly dace, *Phoxinus erythrogaster*, in the Great Lakes basin.




Distribution and conservation status of the longnose sucker, *Catostomus catostomus*, in the Great Lakes basin.




Distribution and conservation status of the creek chubsucker, *Erimyzon oblongus*, in the Great Lakes basin.



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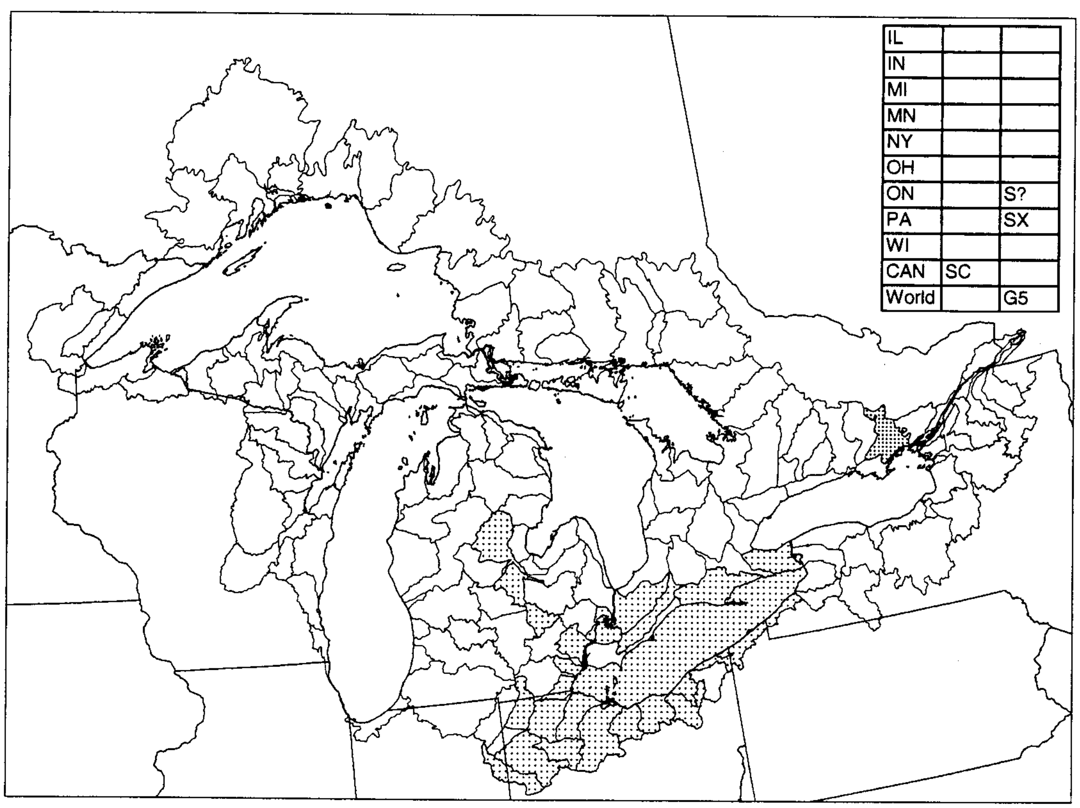
Distribution and conservation status of the lake chubsucker, *Erimyzon succetta*, in the Great Lakes basin.



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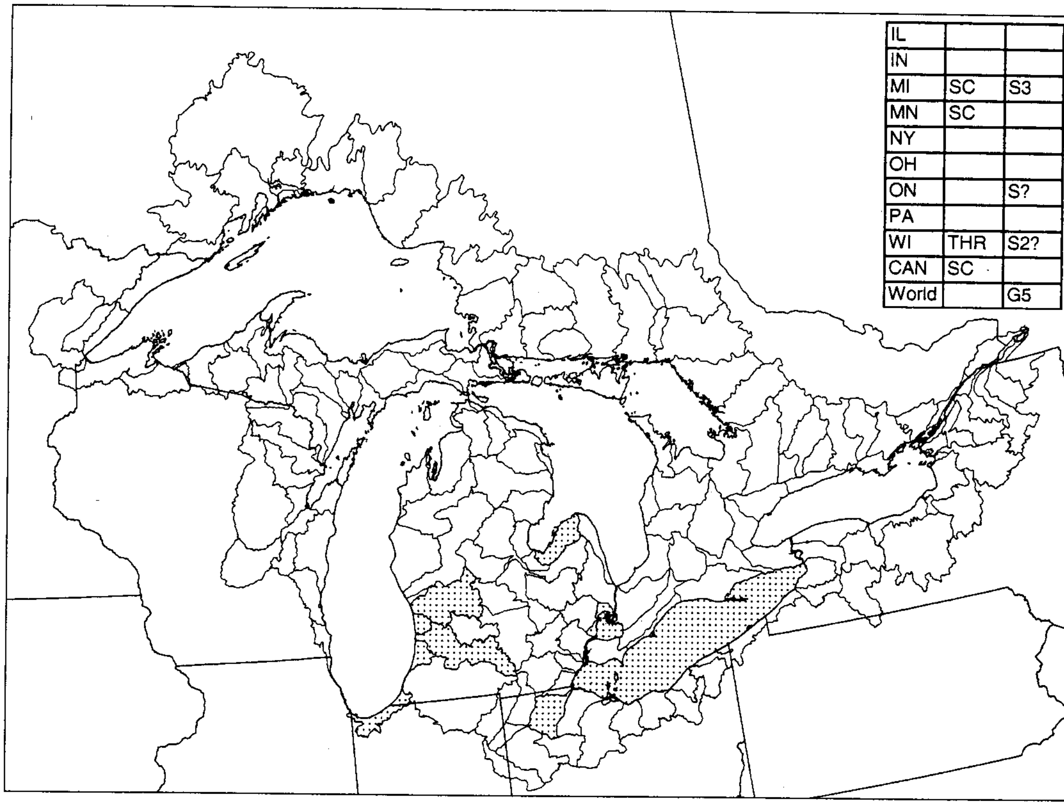
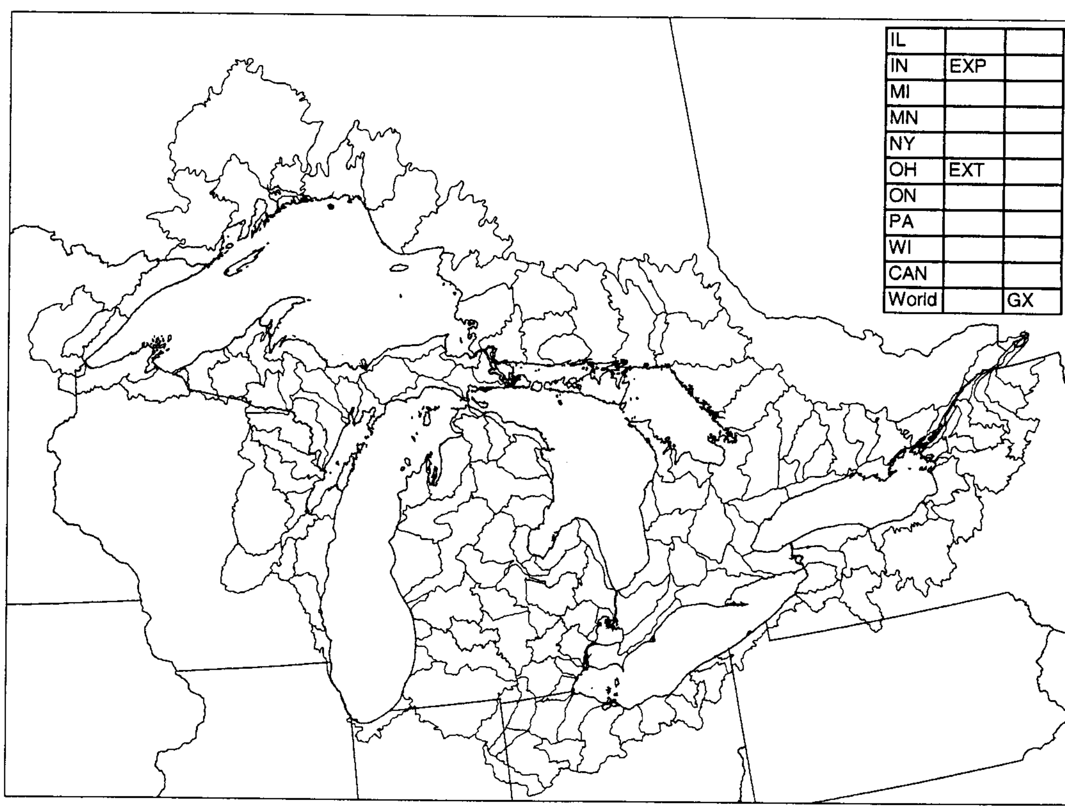
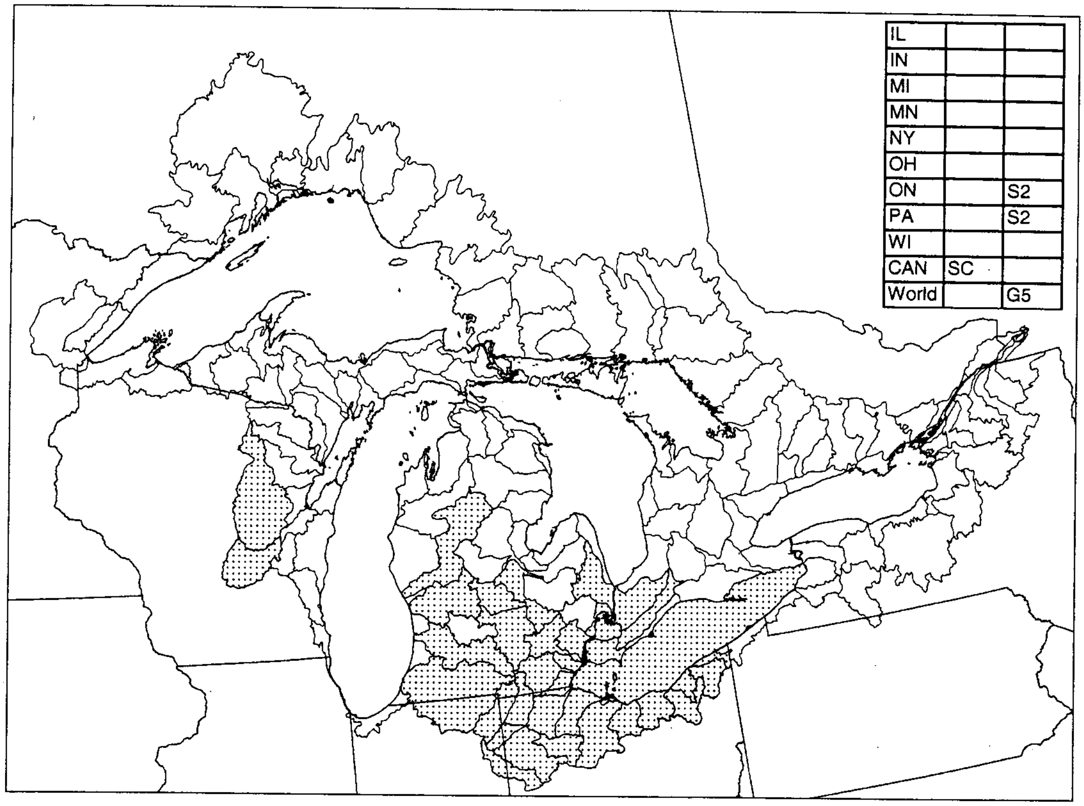
Distribution and conservation status of the bigmouth buffalo, *Ictiobus cyprinellus*, in the Great Lakes basin. Heavy stipple- native; light stipple-introduced.




Distribution and conservation status of the black buffalo, *Ictiobus niger*, in the Great Lakes basin.




Distribution and conservation status of the harelip sucker, *Lagochila lacera*, in the Great Lakes basin.



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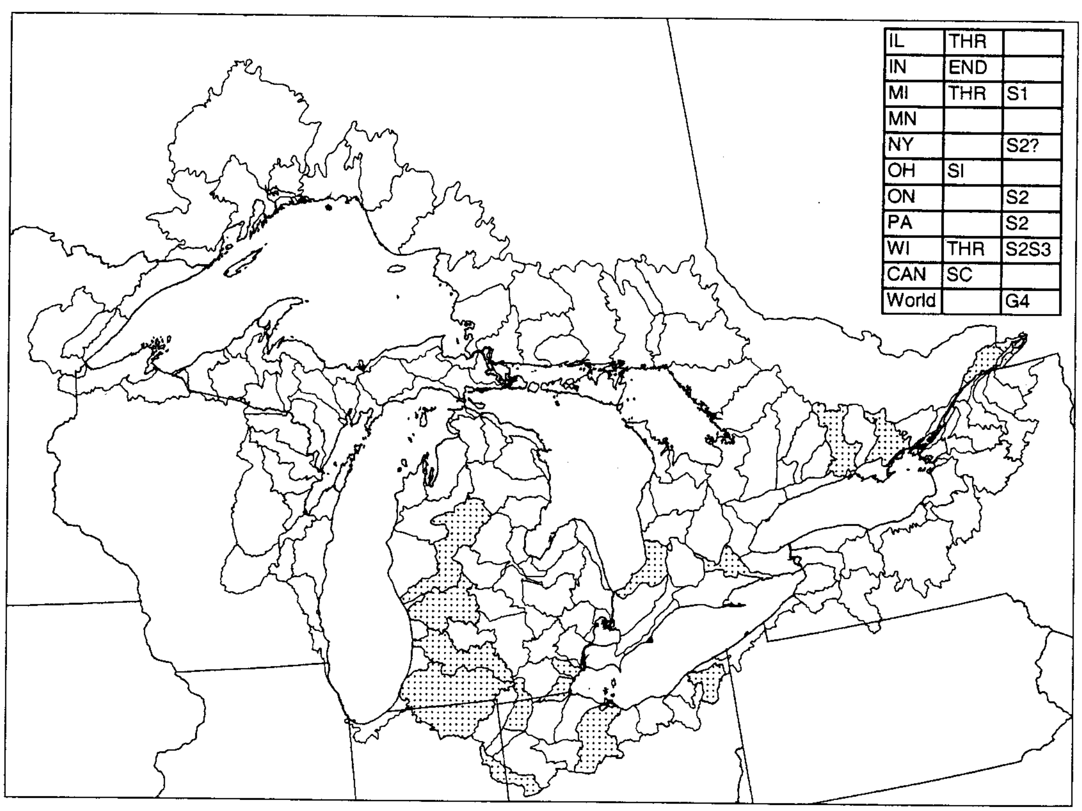
Distribution and conservation status of the spotted sucker, *Minytrema melanops*, in the Great Lakes basin.



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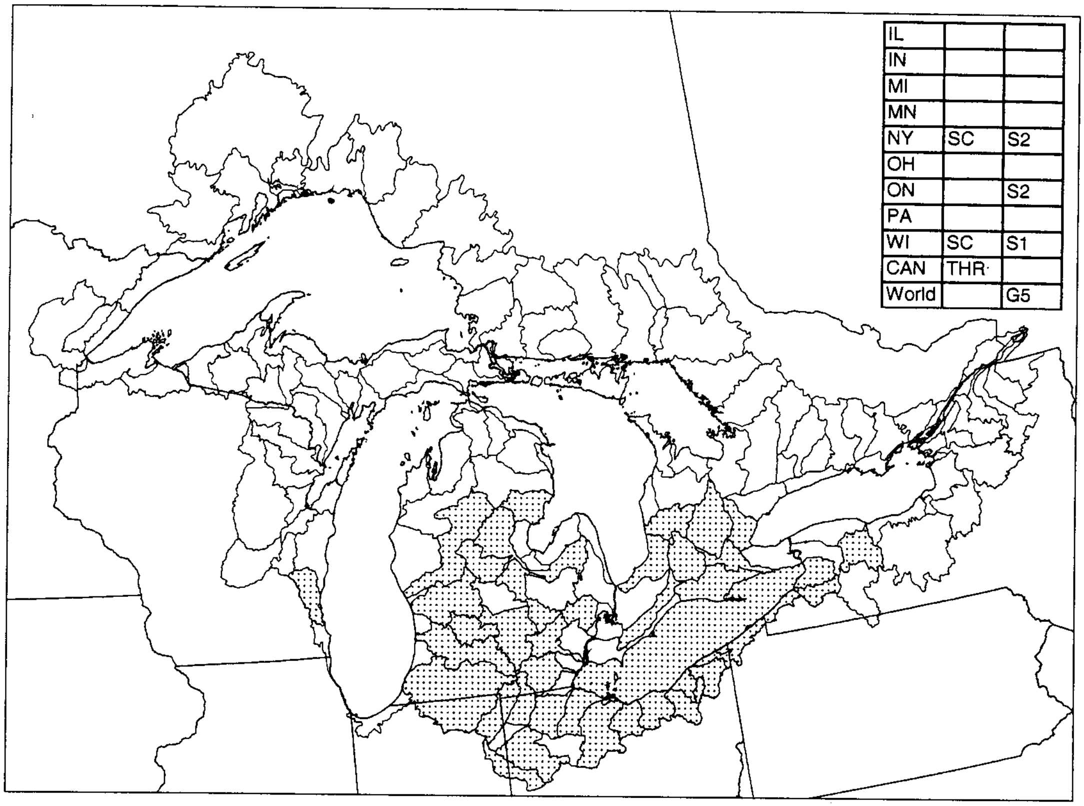
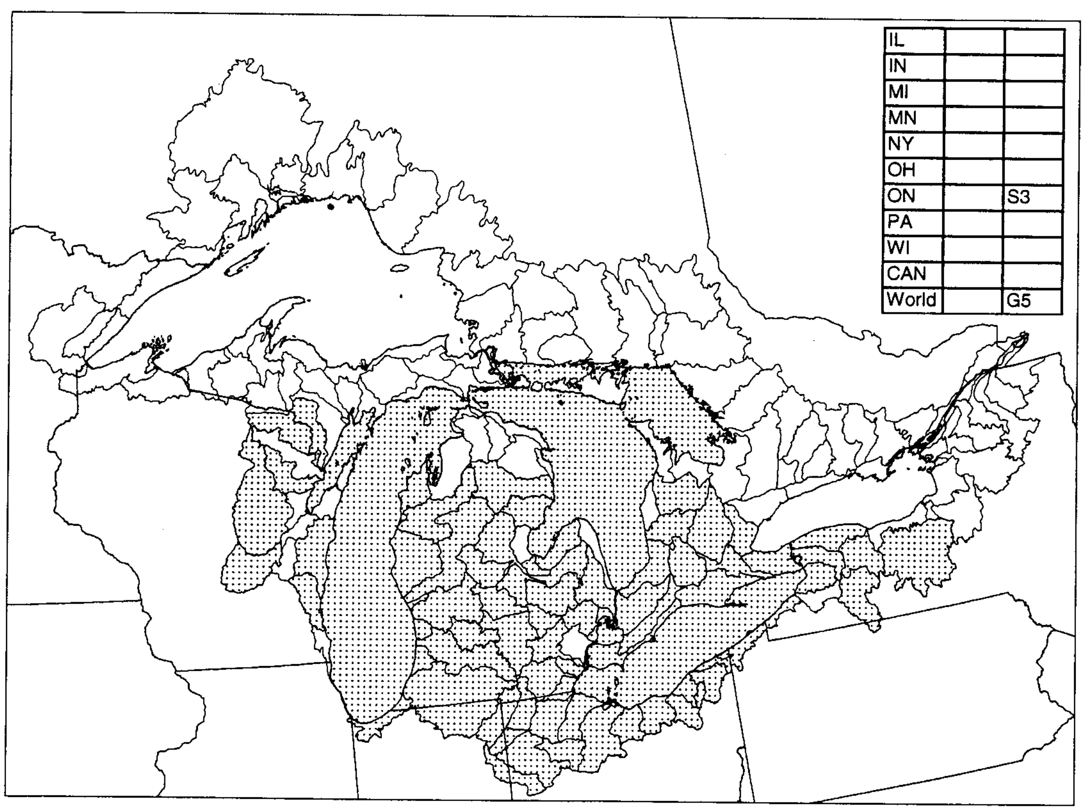
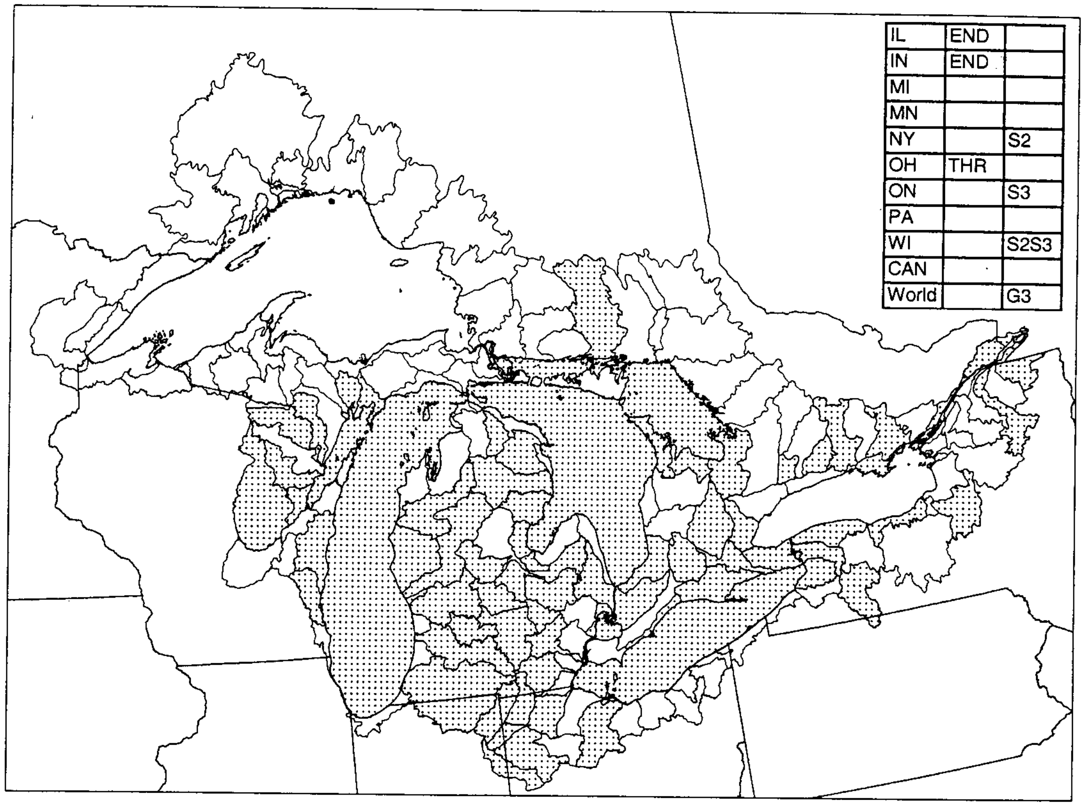
Distribution and conservation status of the river redhorse, *Moxostoma carinatum*, in the Great Lakes basin.



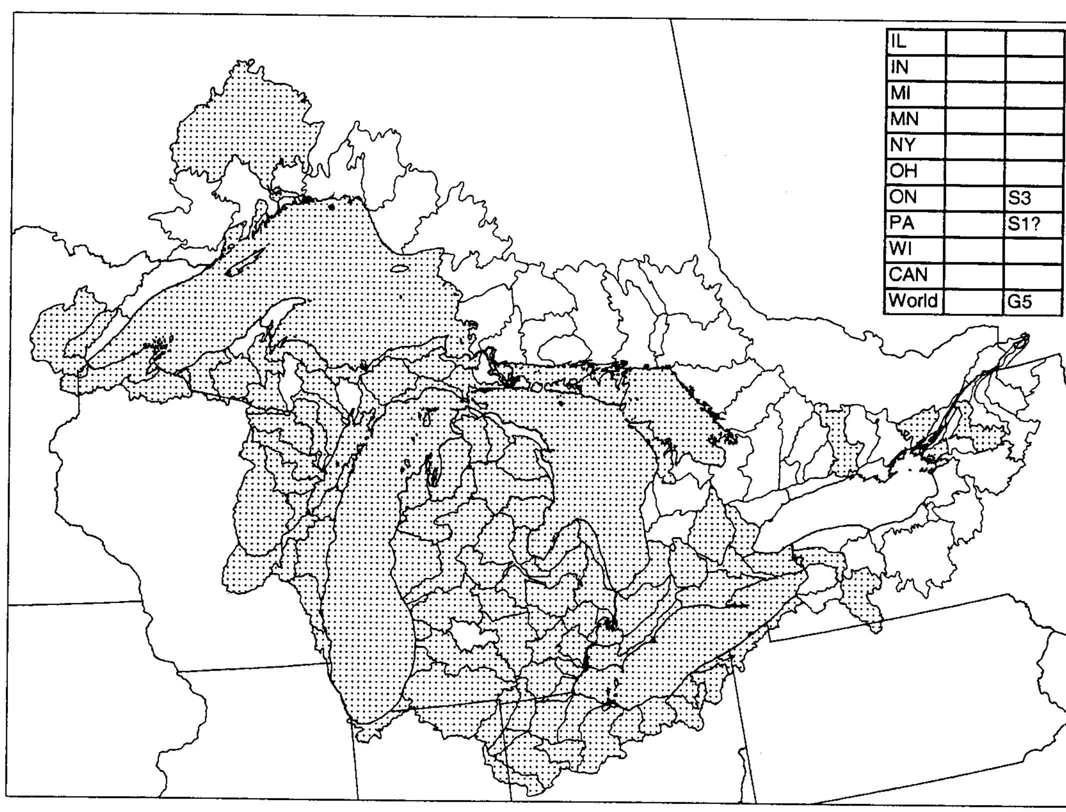

Distribution and conservation status of the black redhorse, *Moxostoma duquesnei*, in the Great Lakes basin.



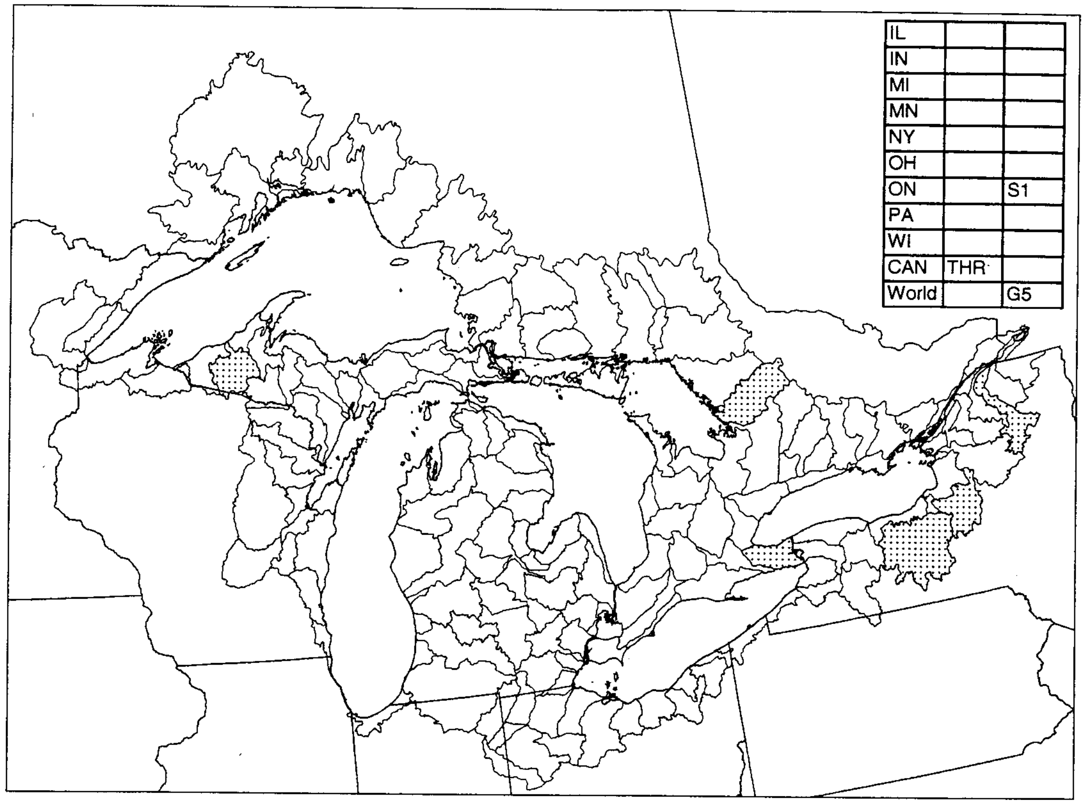

Distribution and conservation status of the golden redhorse, *Moxostoma erythrurum*, in the Great Lakes basin.



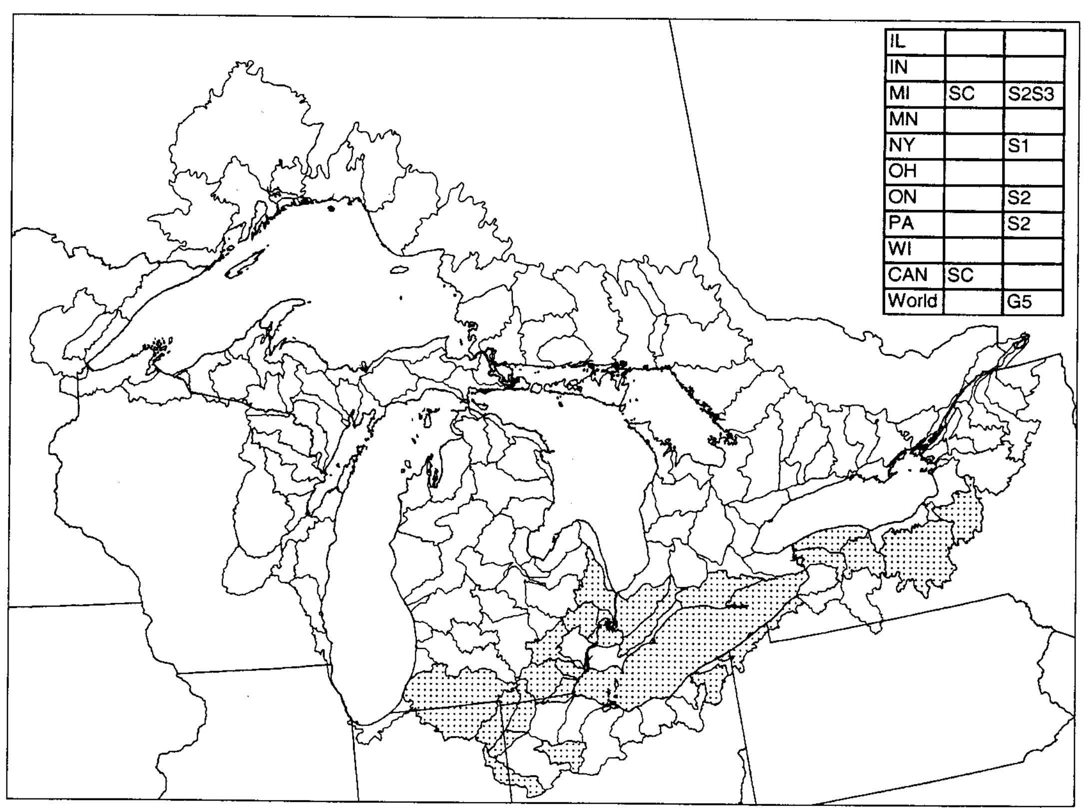

Distribution and conservation status of the greater redhorse, *Moxostoma valenciennesi*, in the Great Lakes basin.



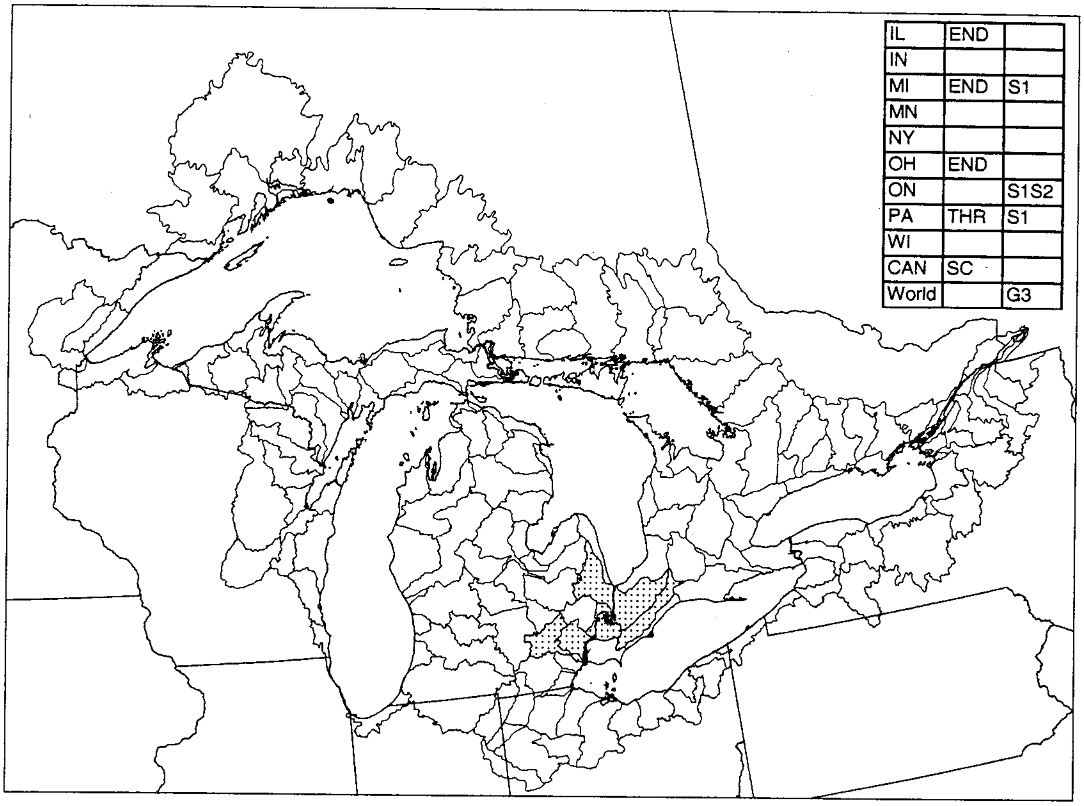

Distribution and conservation status of the black bullhead, *Ameiurus melas*, in the Great Lakes basin.



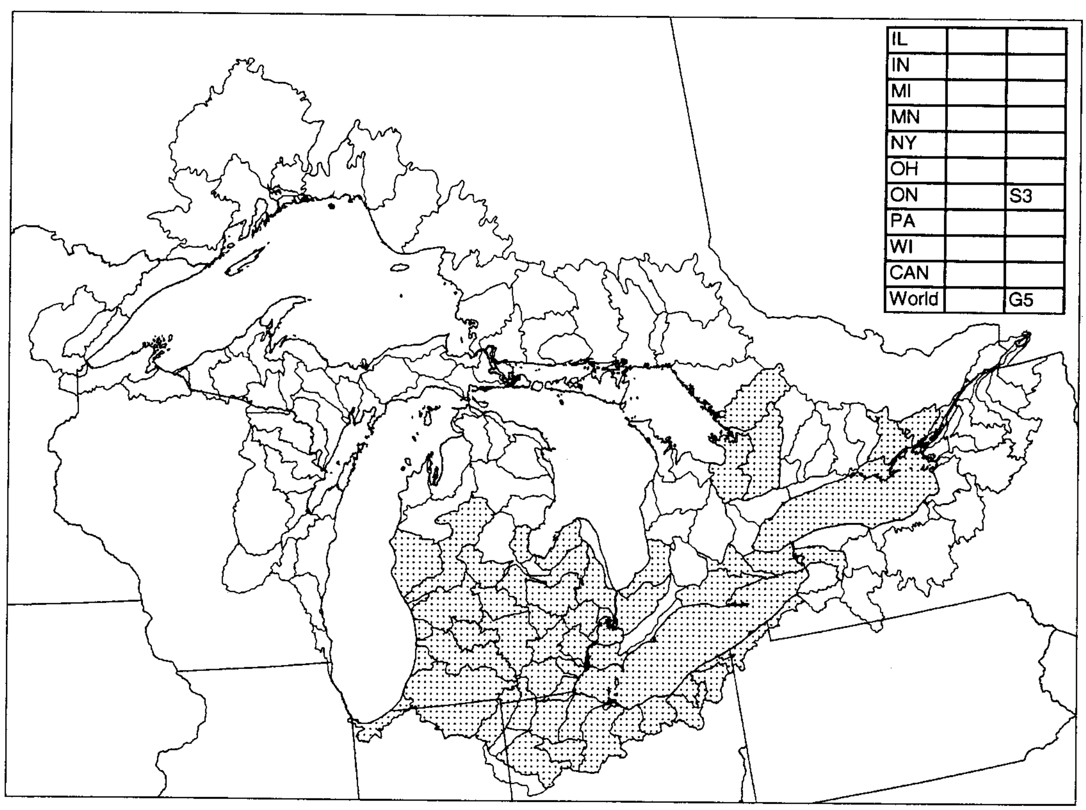

Distribution and conservation status of the margined madtom, *Noturus insignis*, in the Great Lakes basin.



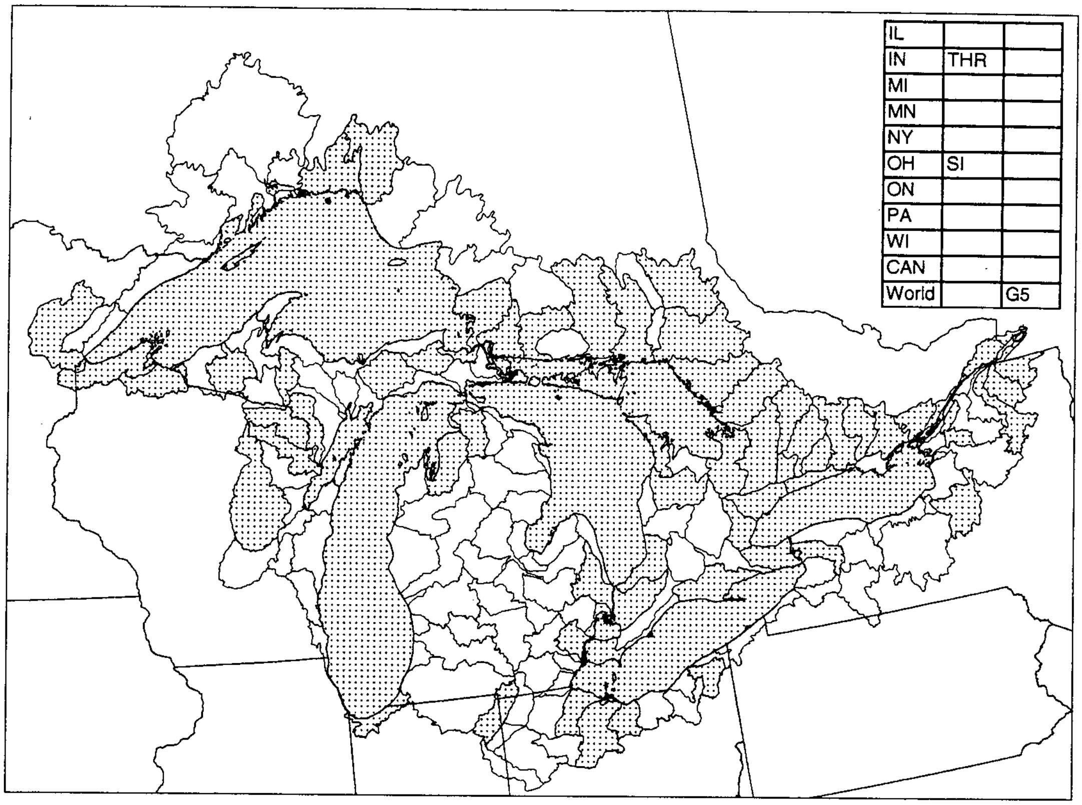

Distribution and conservation status of the brindled madtom, *Noturus miurus*, in the Great Lakes basin.



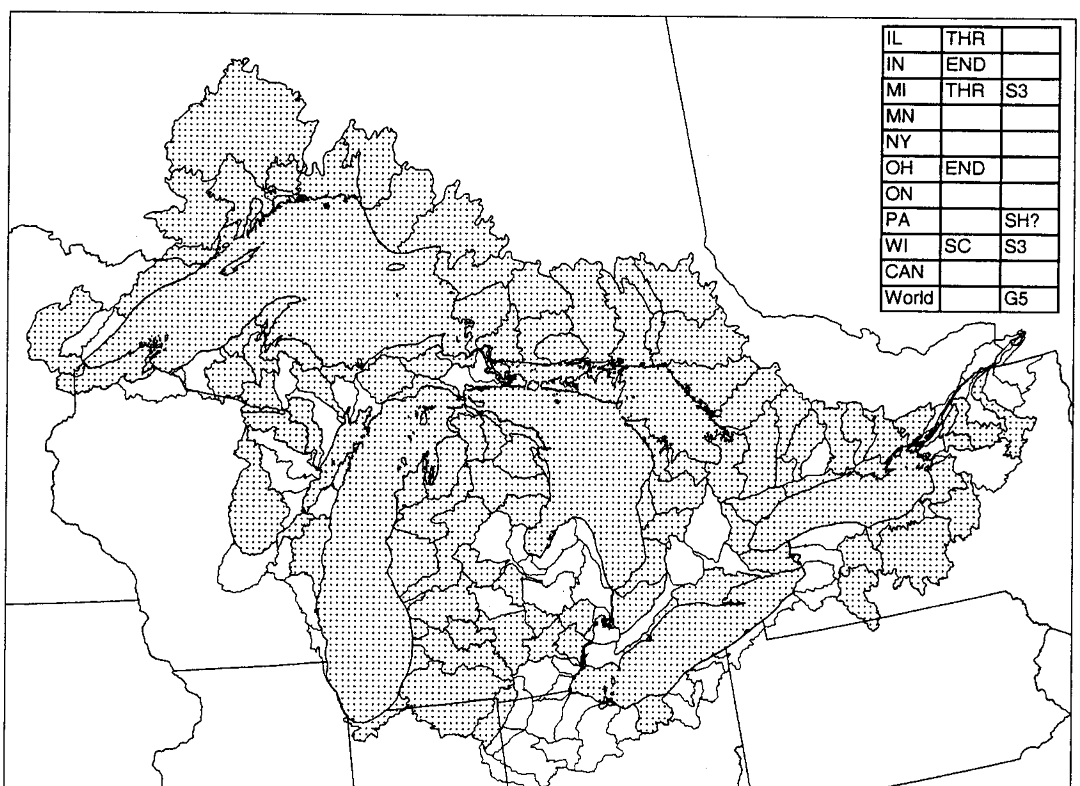

Distribution and conservation status of the northern madtom, *Noturus stigmosus*, in the Great Lakes basin.



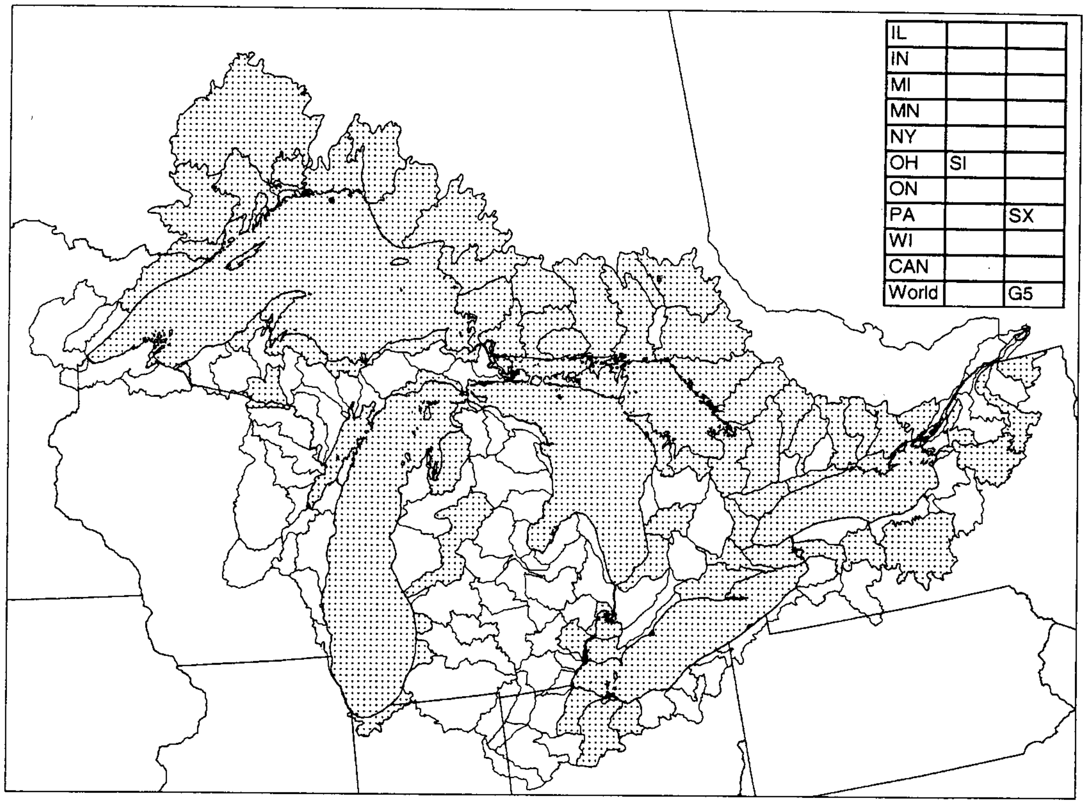

Distribution and conservation status of the grass pickerel, *Esox americanus vermiculatus*, in the Great Lakes basin.



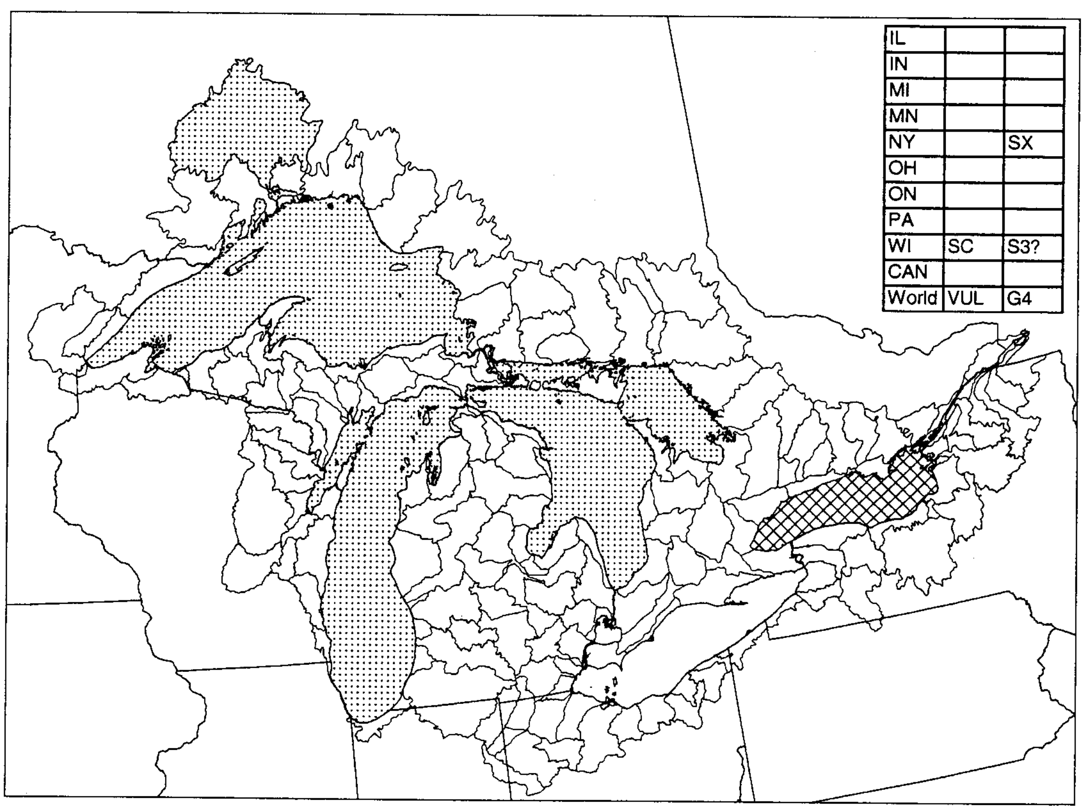

Distribution and conservation status of the muskellunge, *Esox masquinongy*, in the Great Lakes basin.



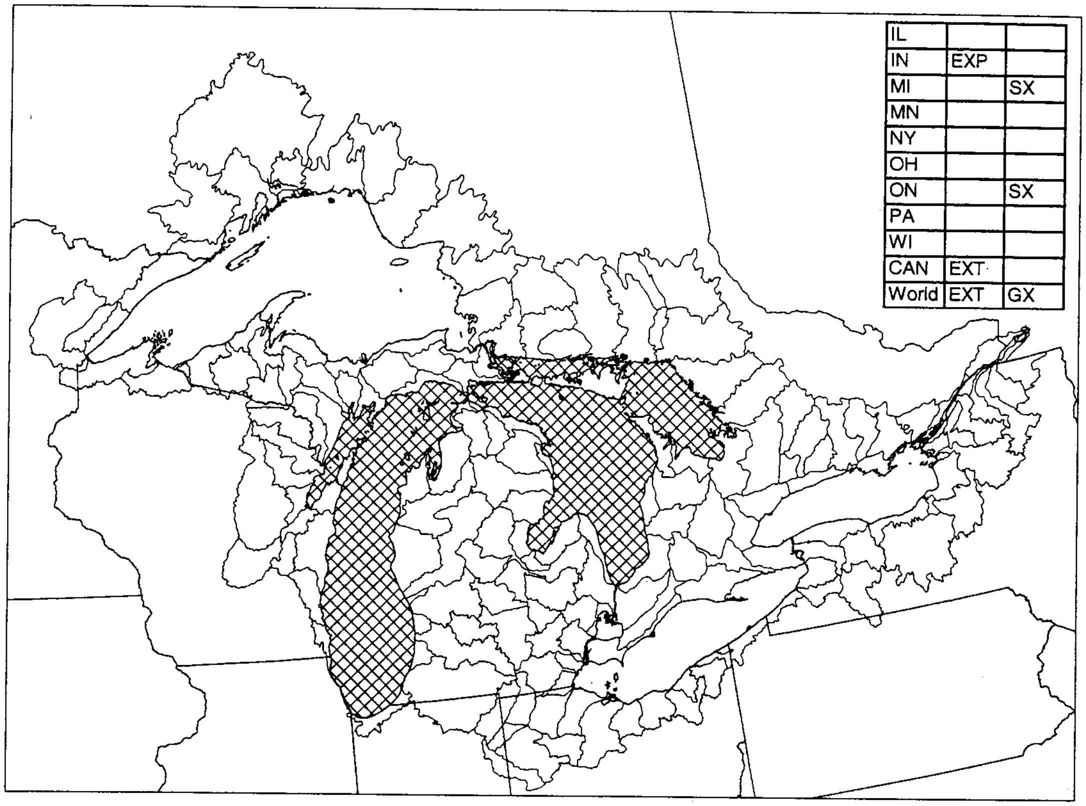

Distribution and conservation status of the cisco, *Coregonus artedi*, in the Great Lakes basin.



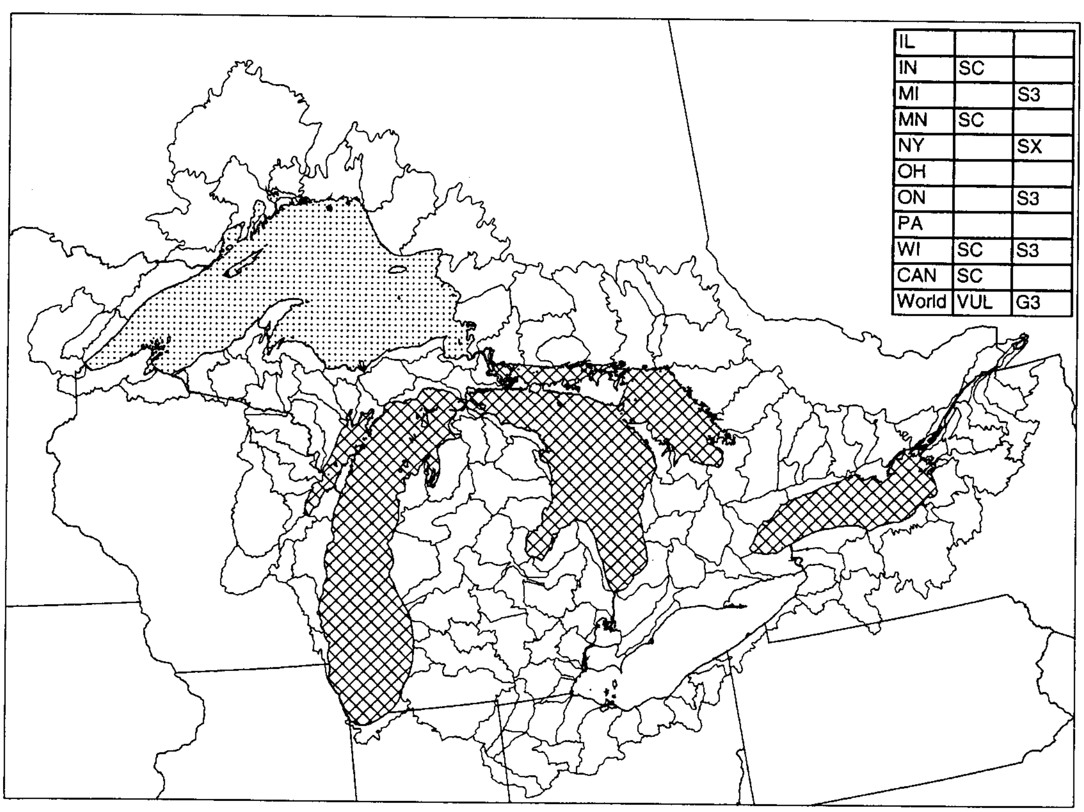

Distribution and conservation status of the lake whitefish, *Coregonus clupeaformis*, in the Great Lakes basin.



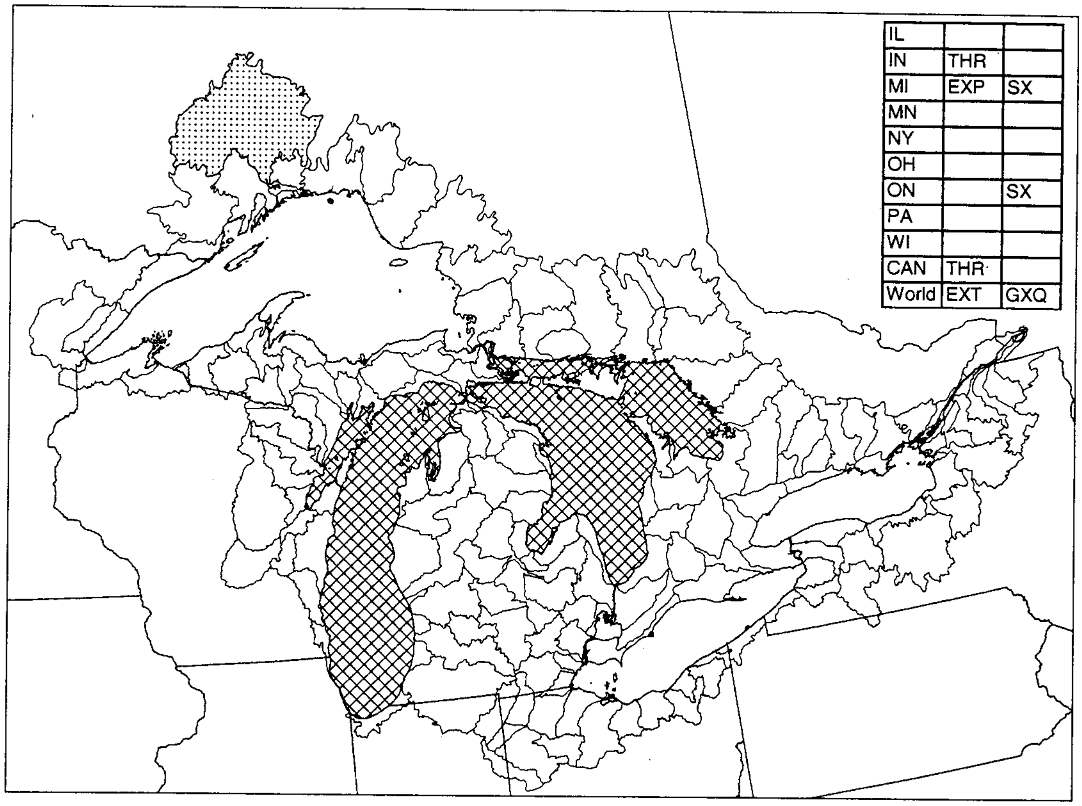

Distribution and conservation status of the bloater, *Coregonus hoyi*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.




Distribution and conservation status of the deepwater cisco, *Coregonus johannae*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.




Distribution and conservation status of the kiyi, *Coregonus kiyi*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.



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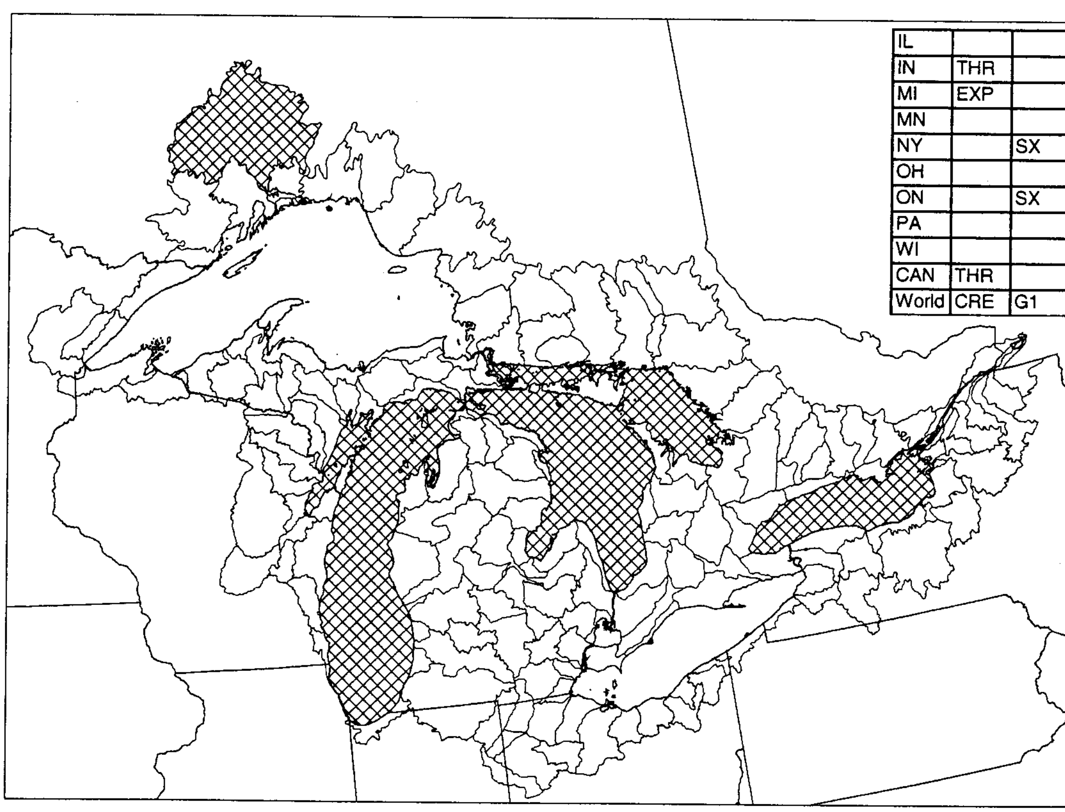
Distribution and conservation status of the blackfin cisco, *Coregonus nigripinnis*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.



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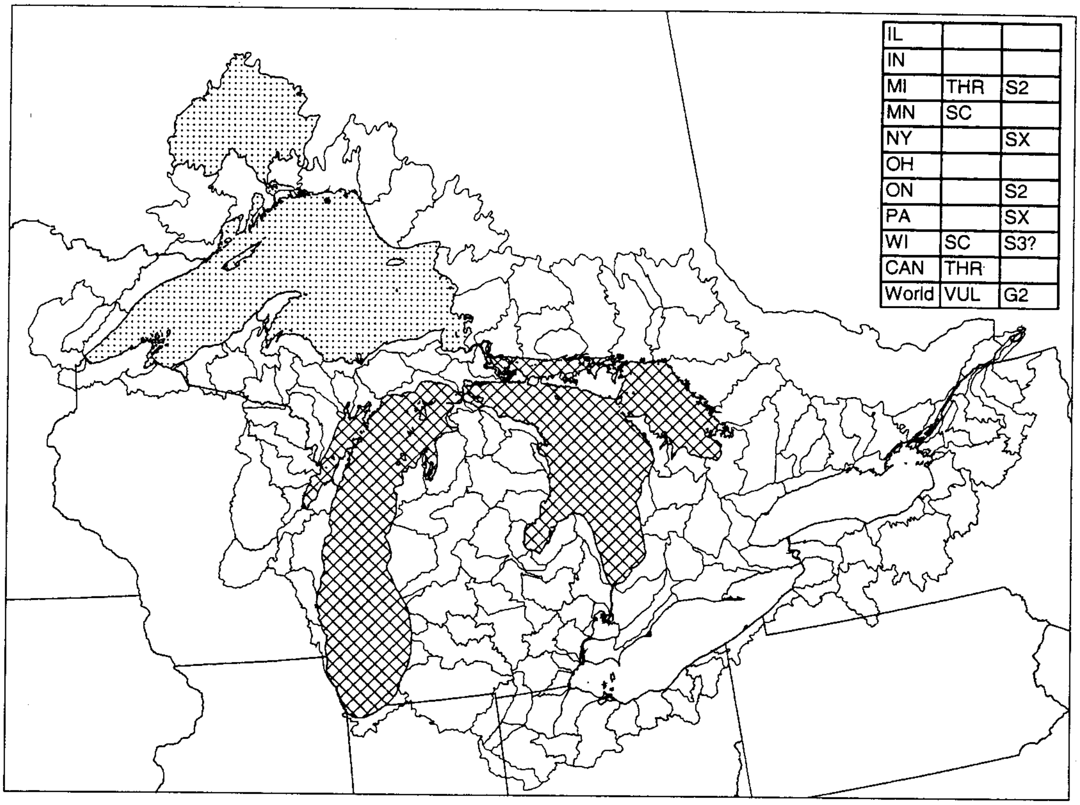
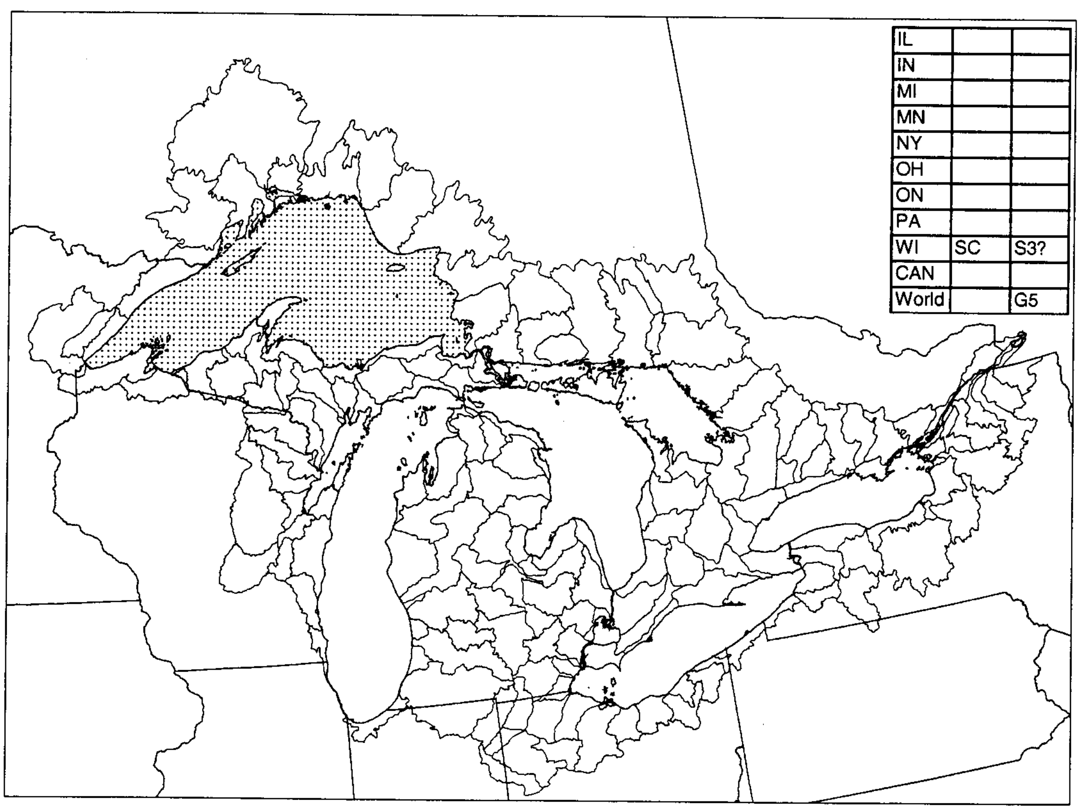
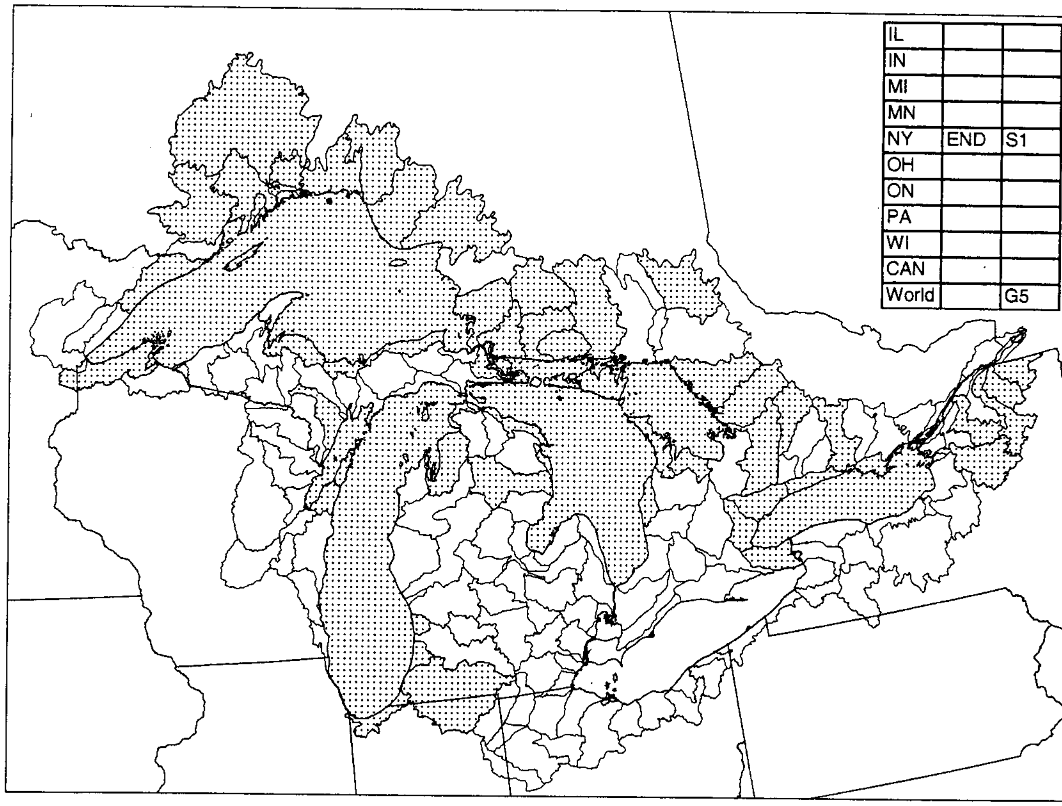
Distribution and conservation status of the shortnose cisco, *Coregonus reighardi*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.



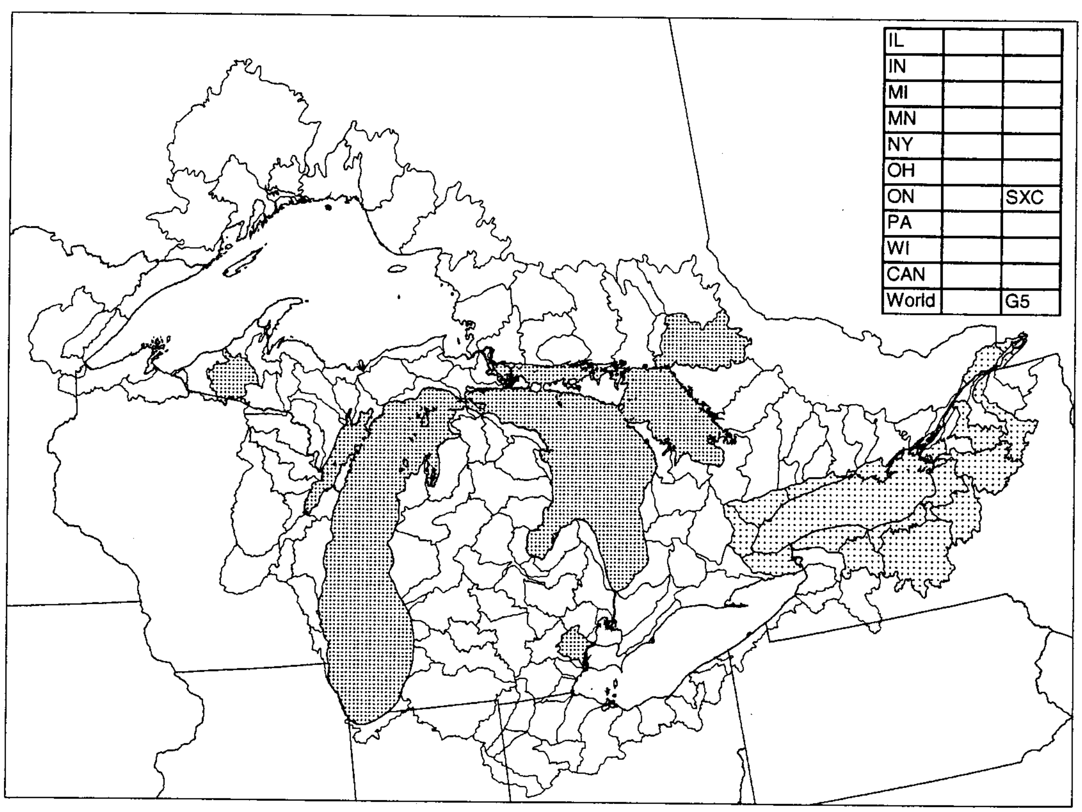

Distribution and conservation status of the shortjaw cisco, *Coregonus zenithicus*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.



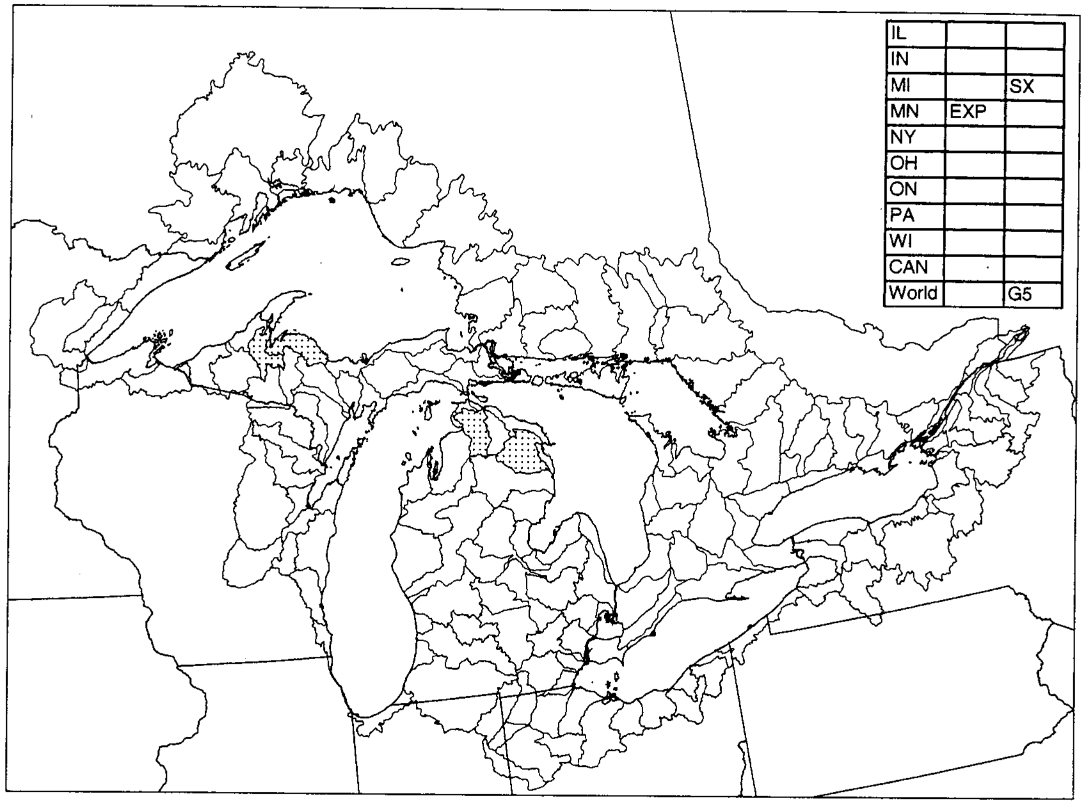

Distribution and conservation status of the pygmy whitefish, *Prosopium coulteri*, in the Great Lakes basin.



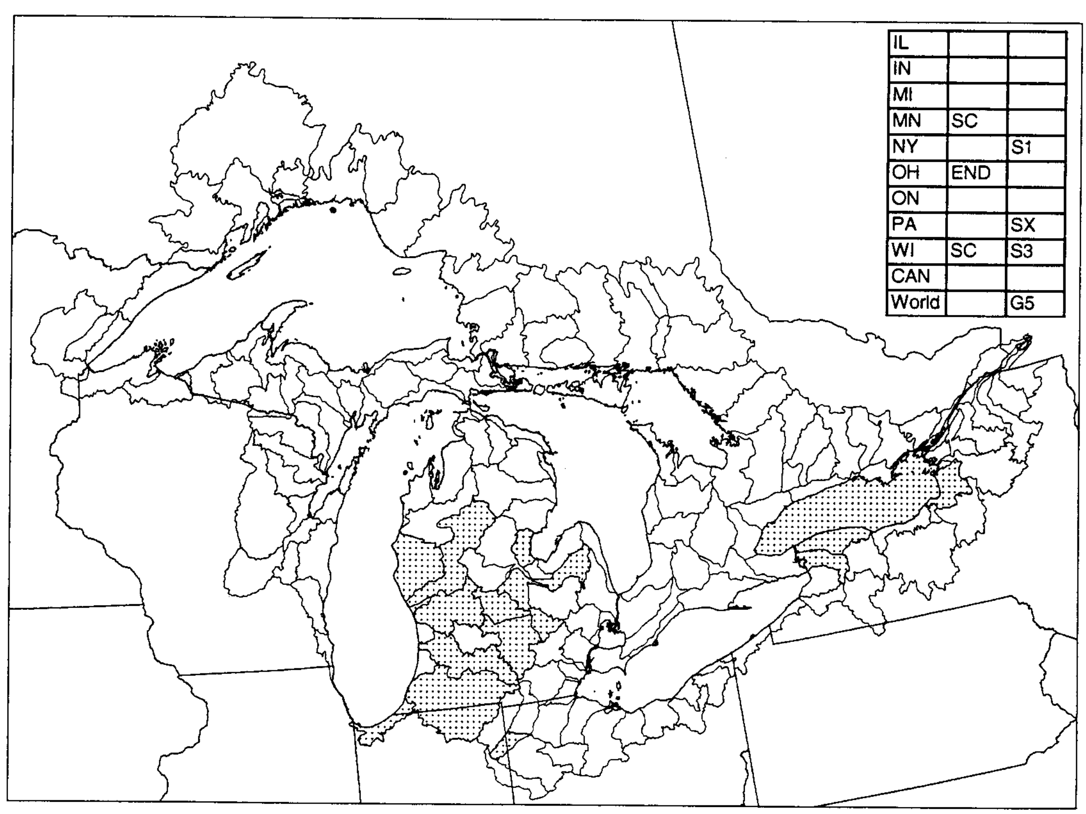

Distribution and conservation status of the round whitefish, *Prosopium cylindraceum*, in the Great Lakes basin.



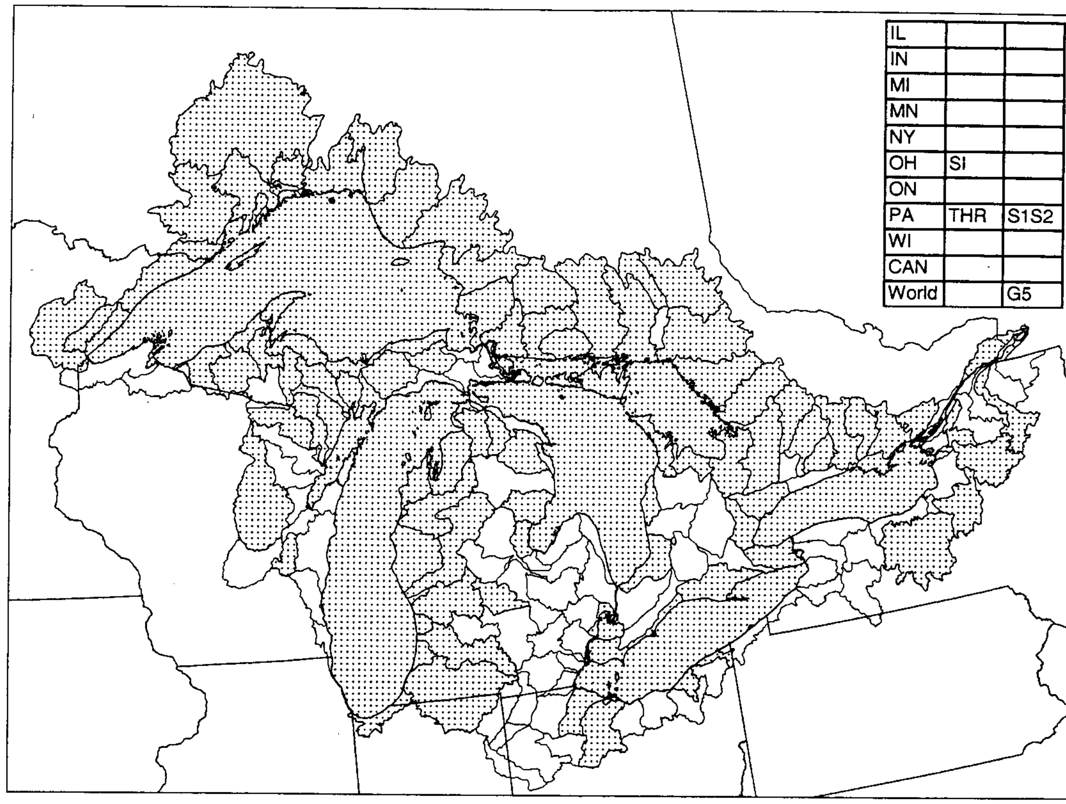

Distribution and conservation status of the Atlantic salmon, *Salmo salar*, in the Great Lakes basin. Heavy stipple- native; light stipple- introduced.



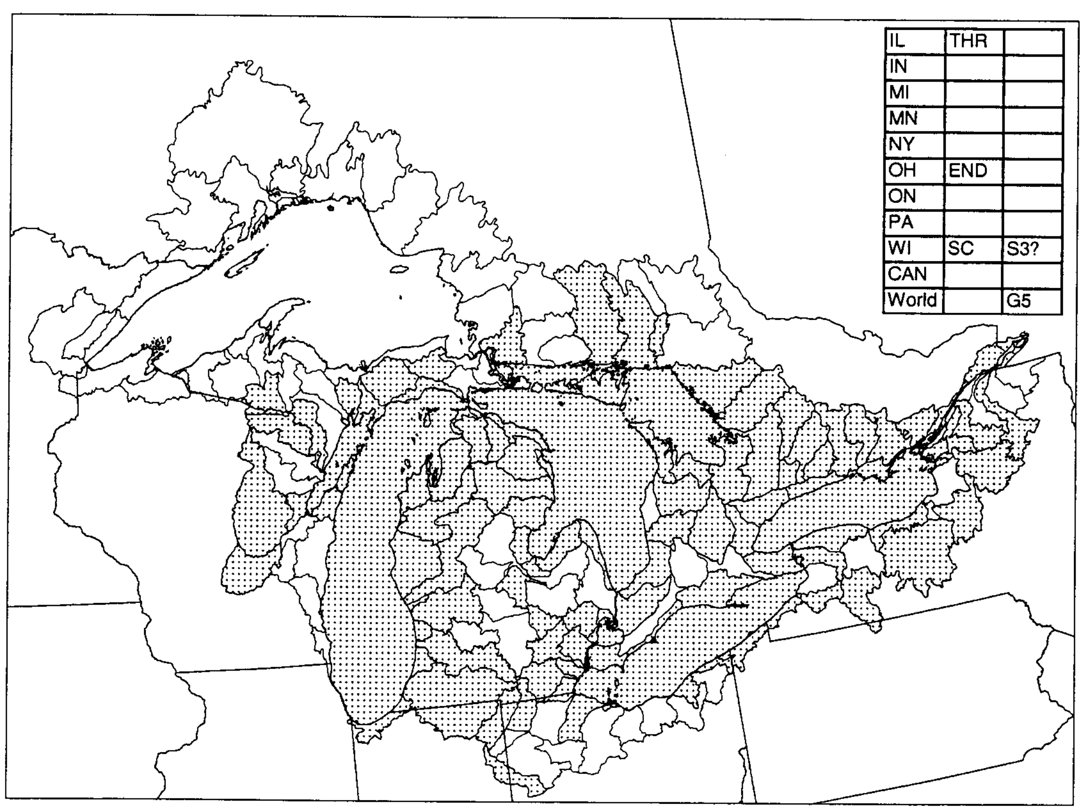

Distribution and conservation status of the Arctic grayling, *Thymallus arcticus*, in the Great Lakes basin.



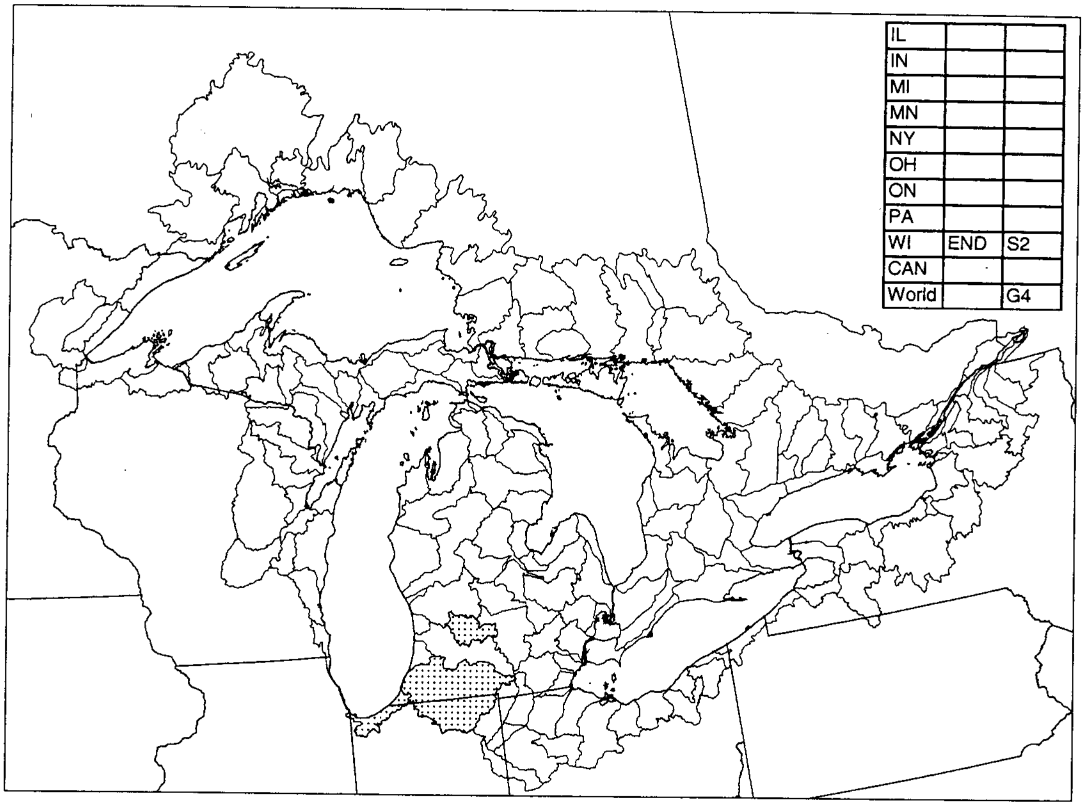

Distribution and conservation status of the pirate perch, *Aphredoderus sayanus*, in the Great Lakes basin.



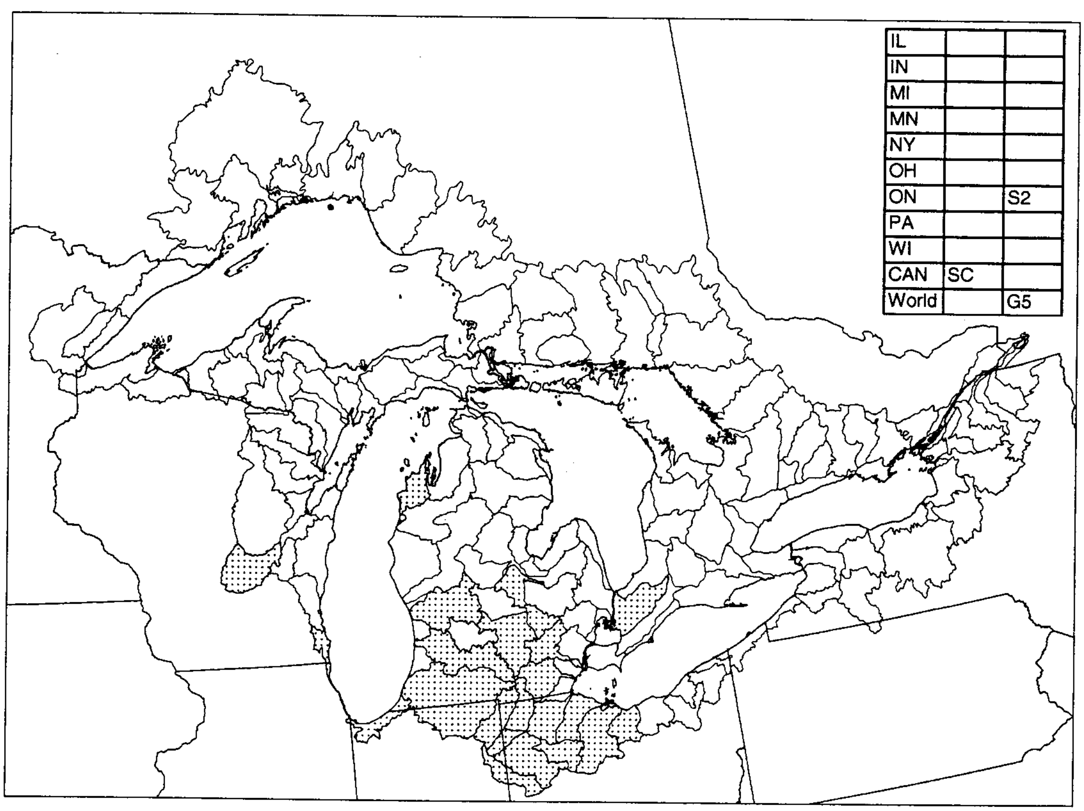

Distribution and conservation status of the burbot, *Lota lota*, in the Great Lakes basin.



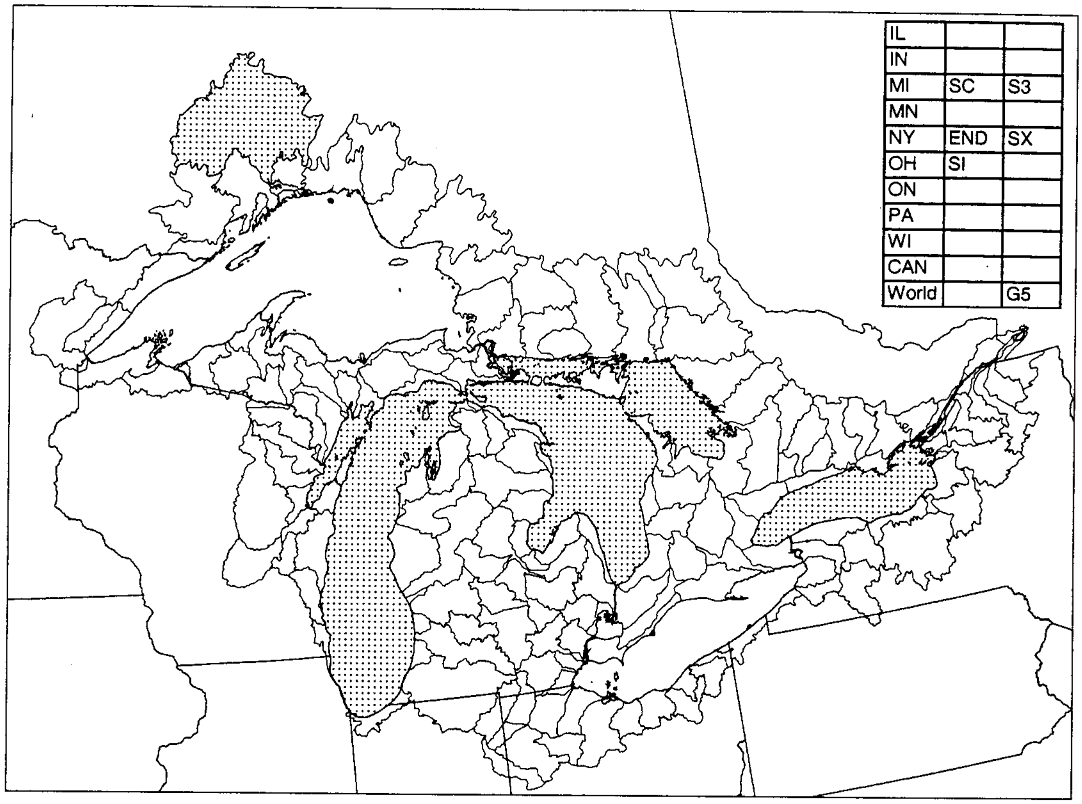

Distribution and conservation status of the banded killifish, *Fundulus diaphanus*, in the Great Lakes basin.



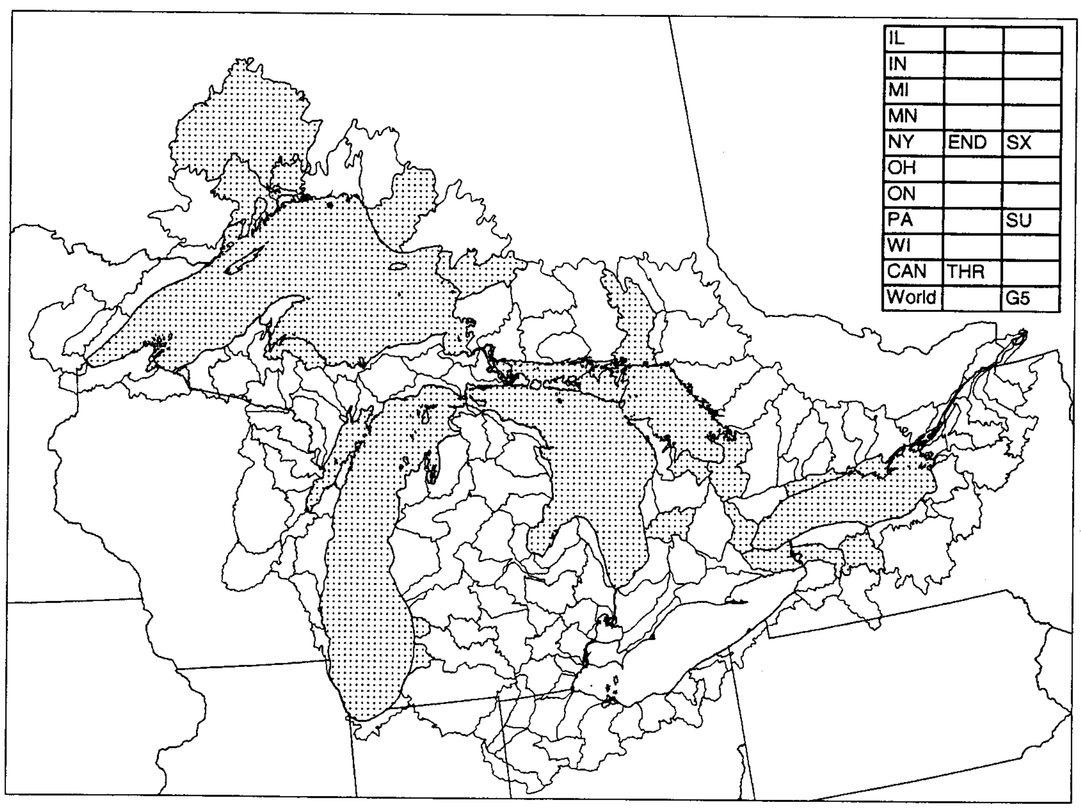

Distribution and conservation status of the starhead topminnow, *Fundulus dispar*, in the Great Lakes basin.



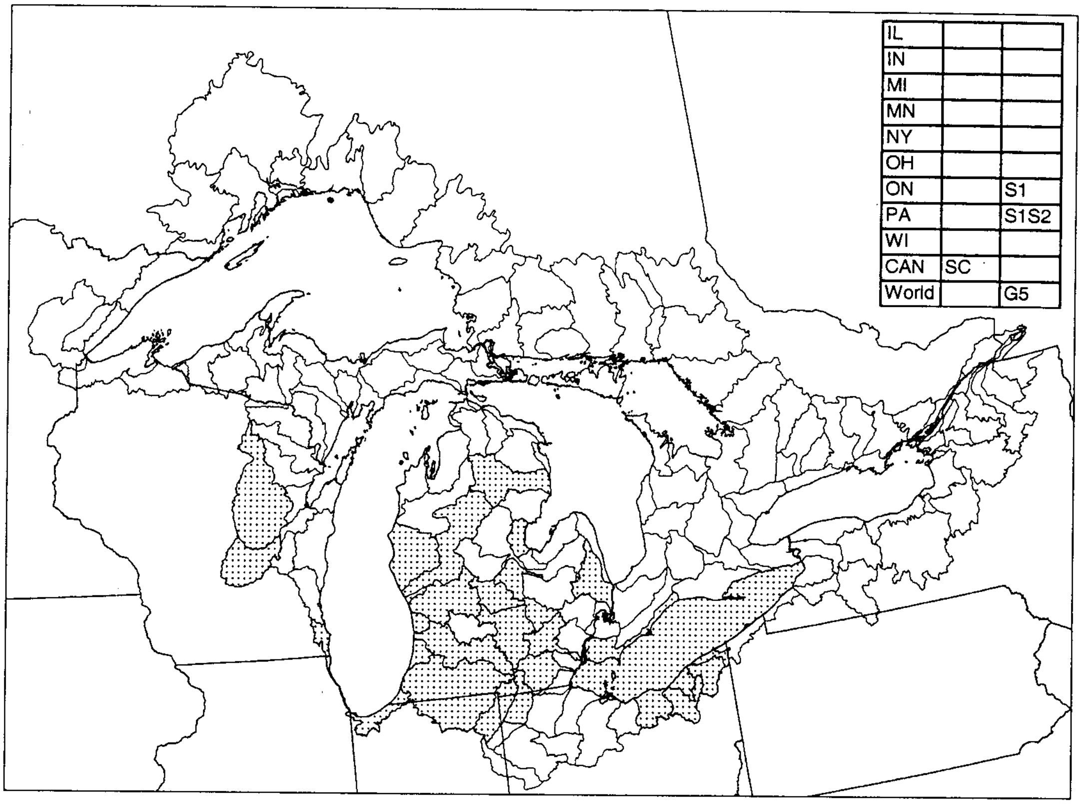

Distribution and conservation status of the blackstripe topminnow, *Fundulus notatus*, in the Great Lakes basin.



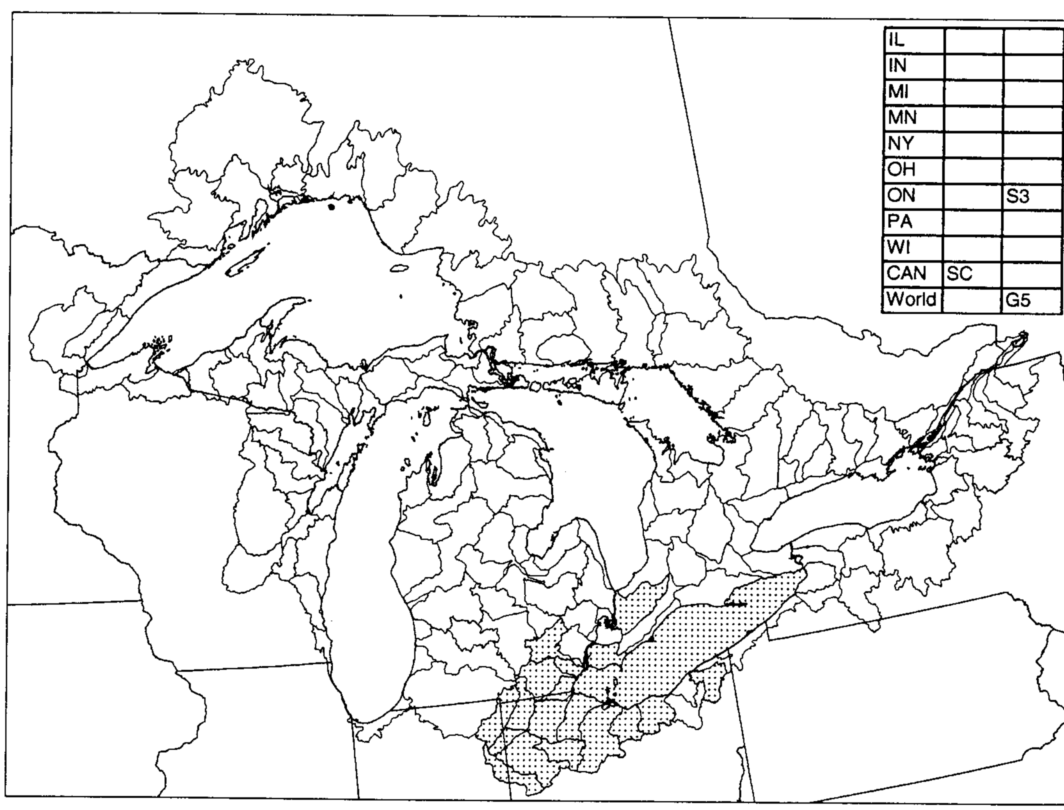

Distribution and conservation status of the spoonhead sculpin, *Cottus ricei*, in the Great Lakes basin.



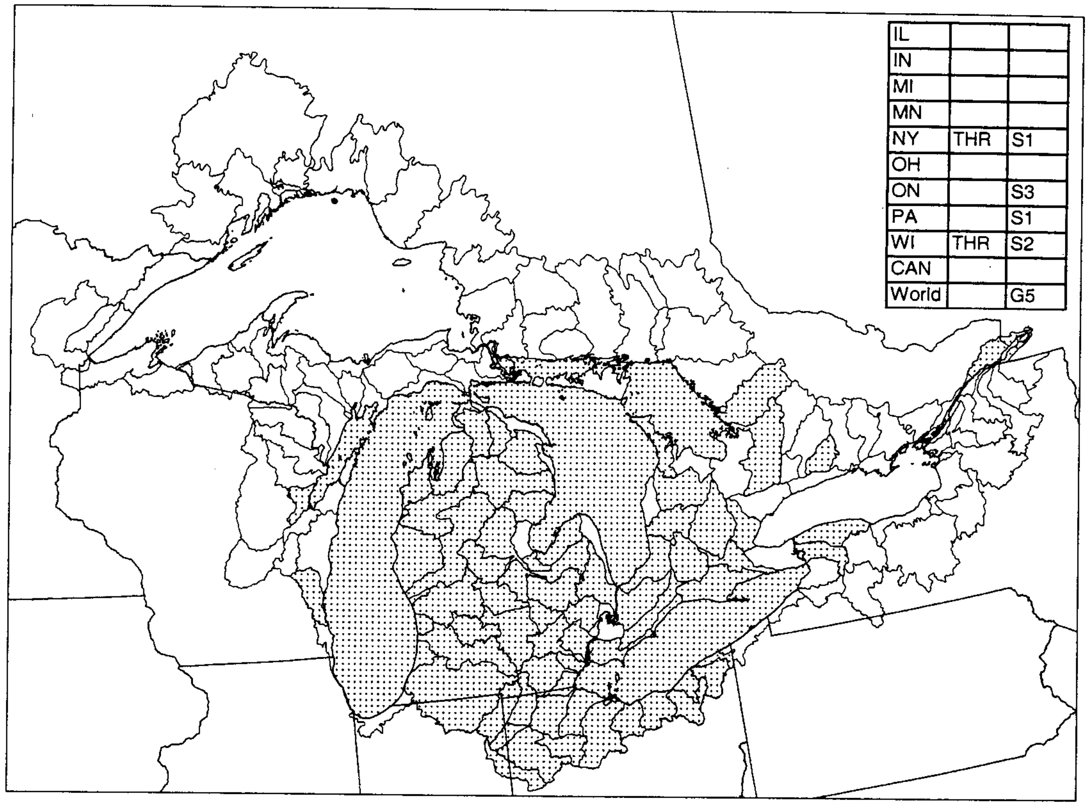

Distribution and conservation status of the deepwater sculpin, *Myoxocephalus thompsoni*, in the Great Lakes basin.



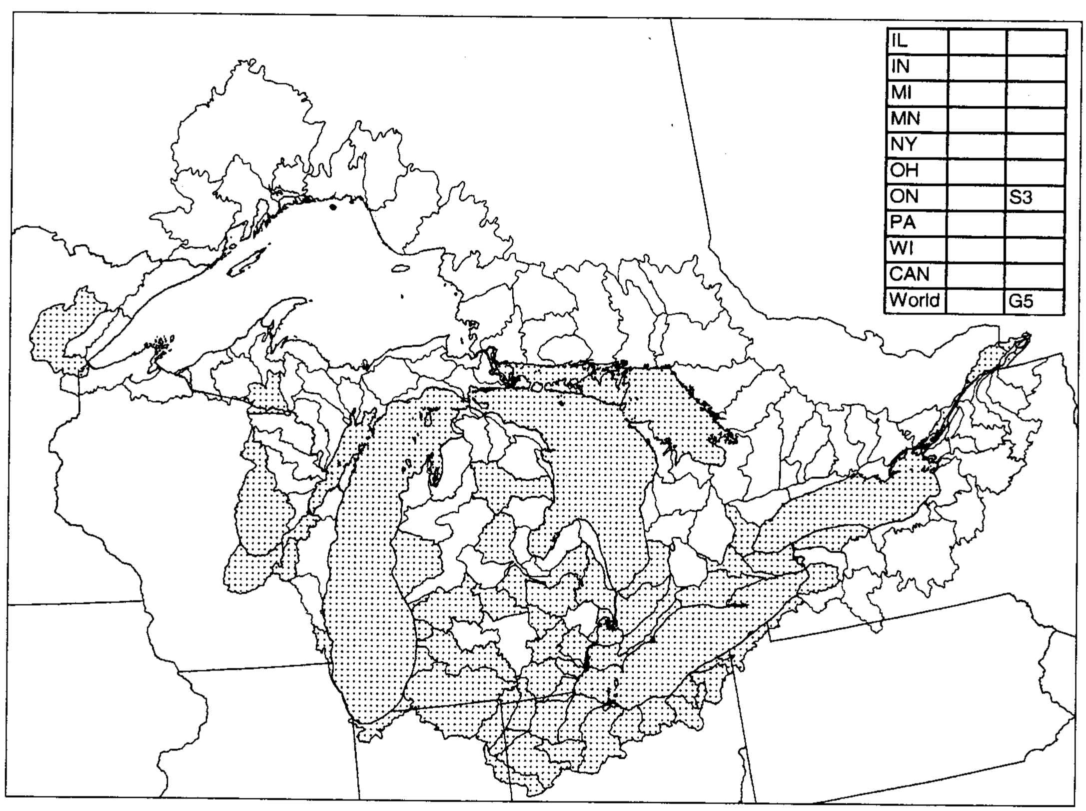

Distribution and conservation status of the warmouth, *Lepomis gulosus*, in the Great Lakes basin.



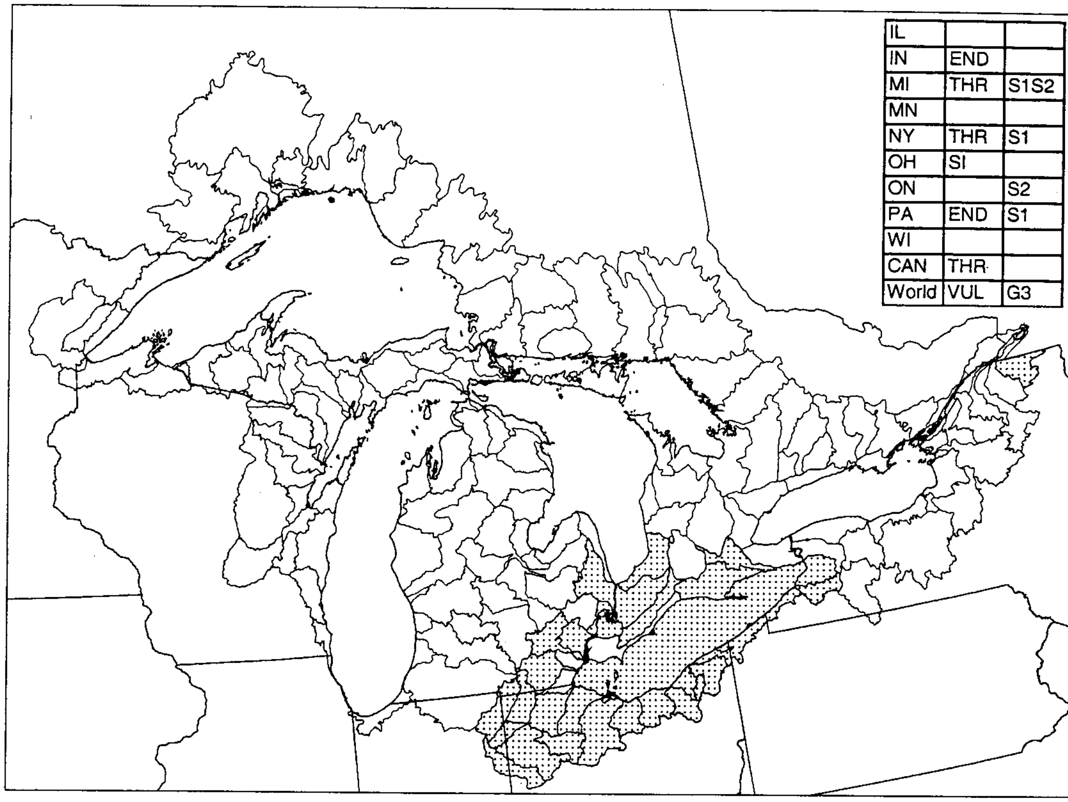

Distribution and conservation status of the orangespotted sunfish, *Lepomis humilis*, in the Great Lakes basin.



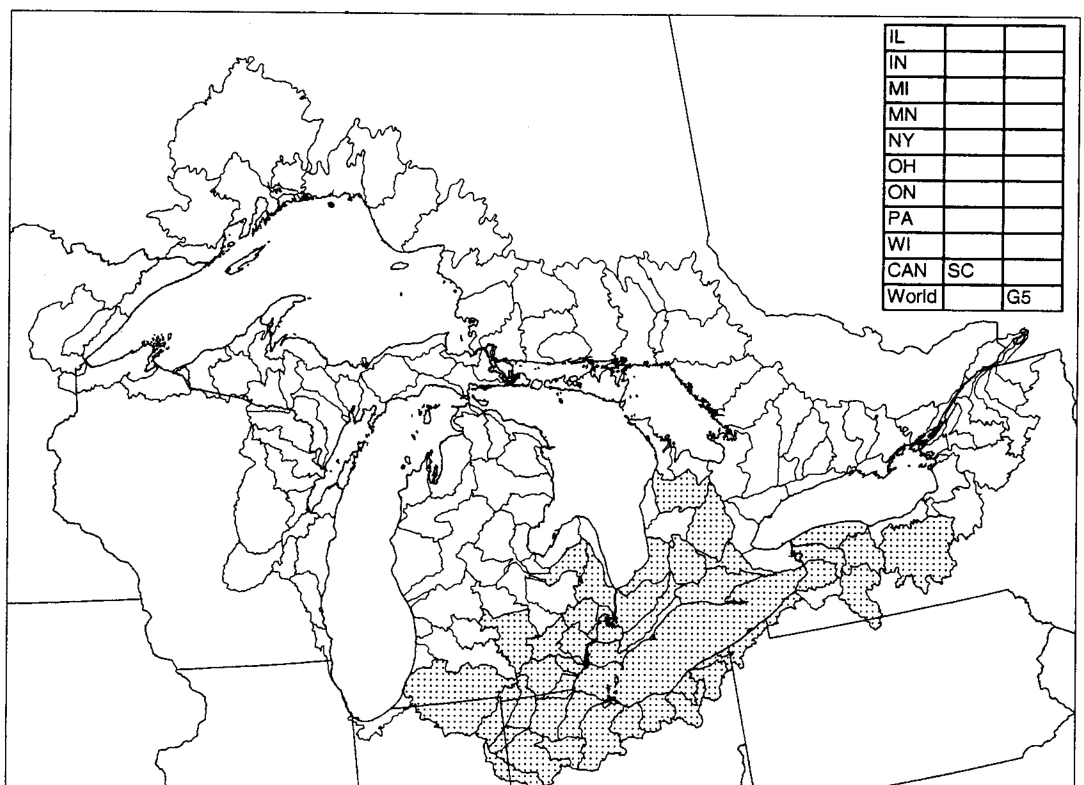

Distribution and conservation status of the longear sunfish, *Lepomis megalotis*, in the Great Lakes basin.



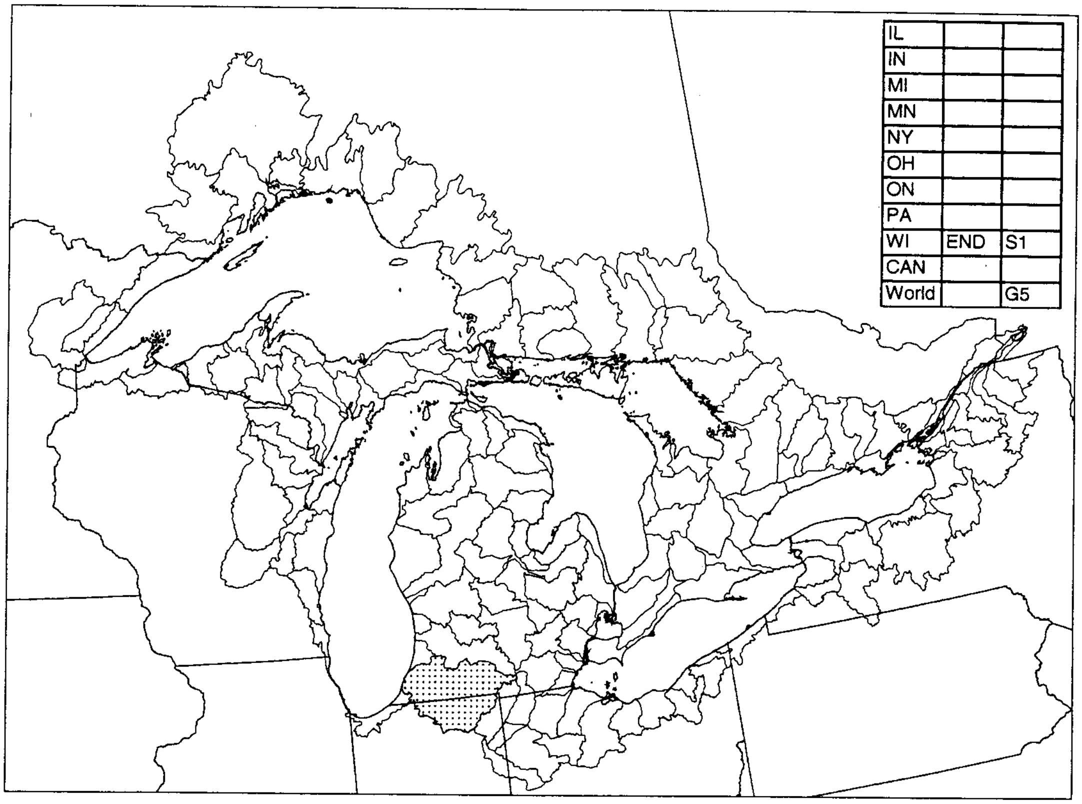

Distribution and conservation status of the white crappie, *Pomoxis annularis*, in the Great Lakes basin.



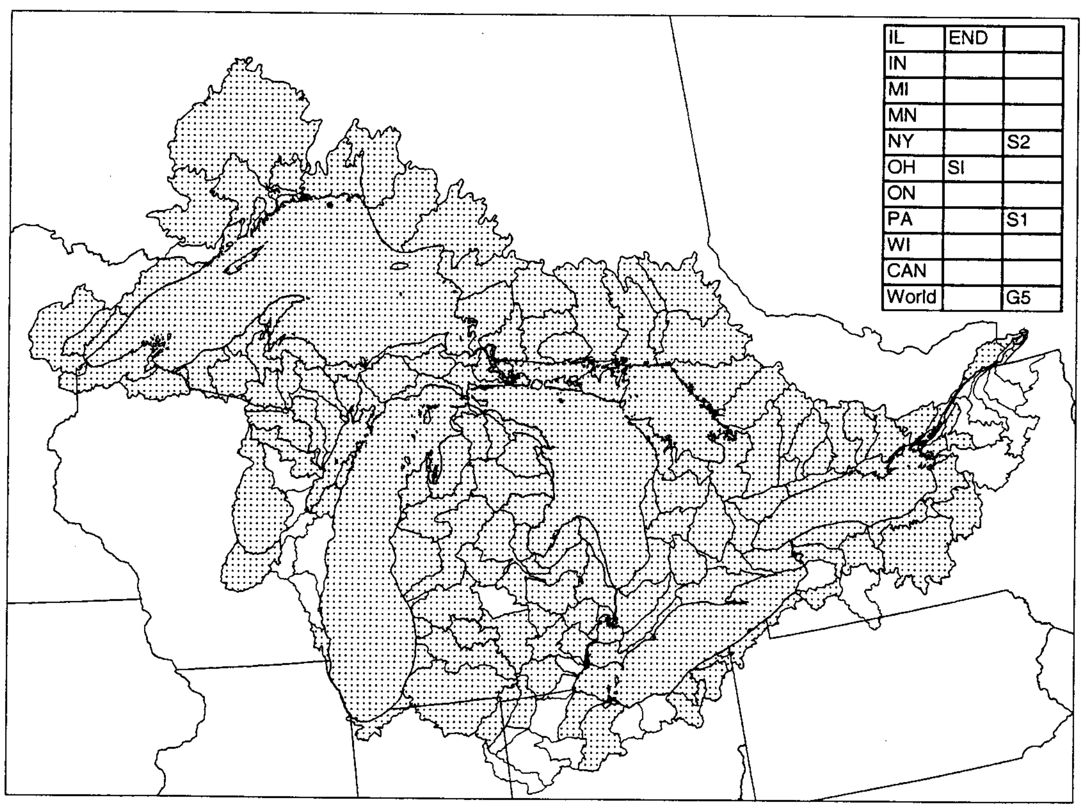

Distribution and conservation status of the eastern sand darter, *Ammocrypta pellucida*, in the Great Lakes basin.



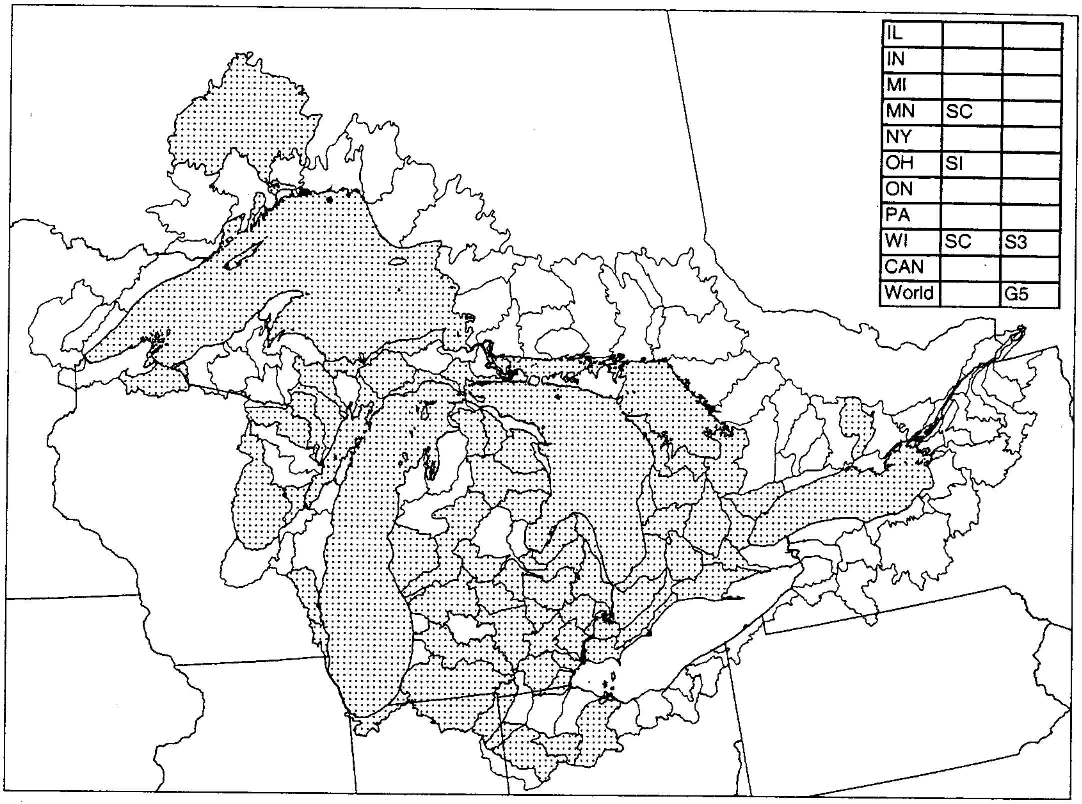

Distribution and conservation status of the greenside darter, *Etheostoma blennioides*, in the Great Lakes basin.



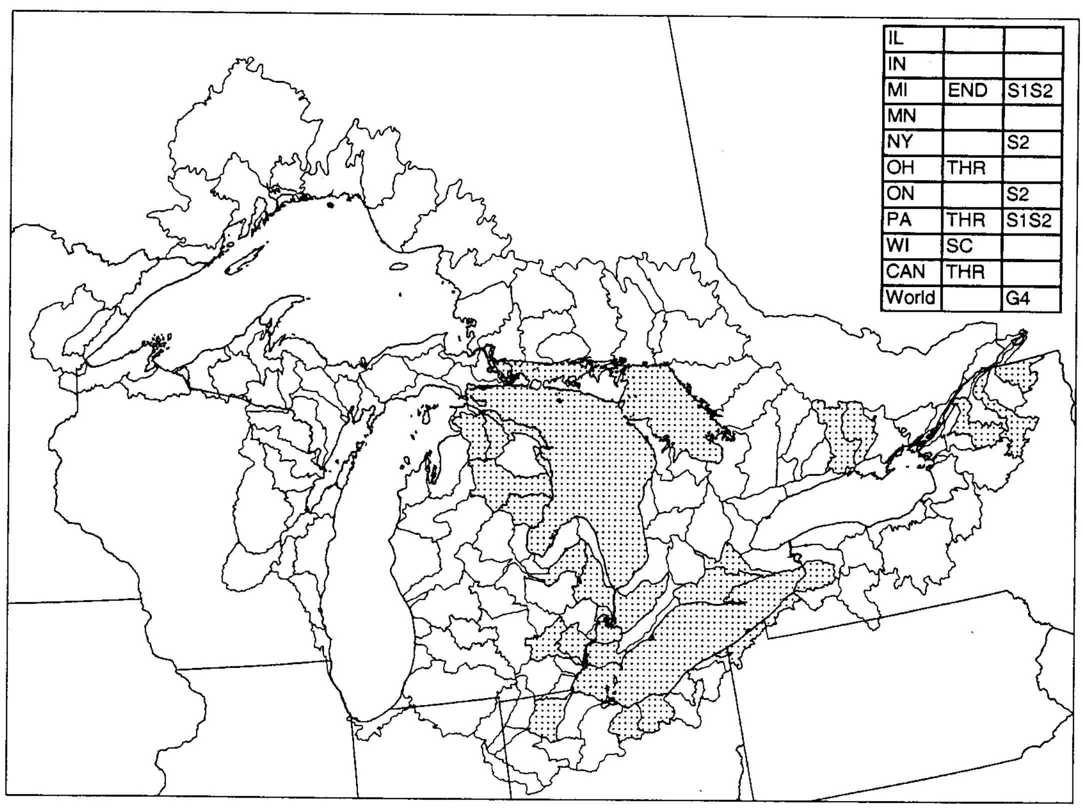

Distribution and conservation status of the bluntnose darter, *Etheostoma chlorosomum*, in the Great Lakes basin.



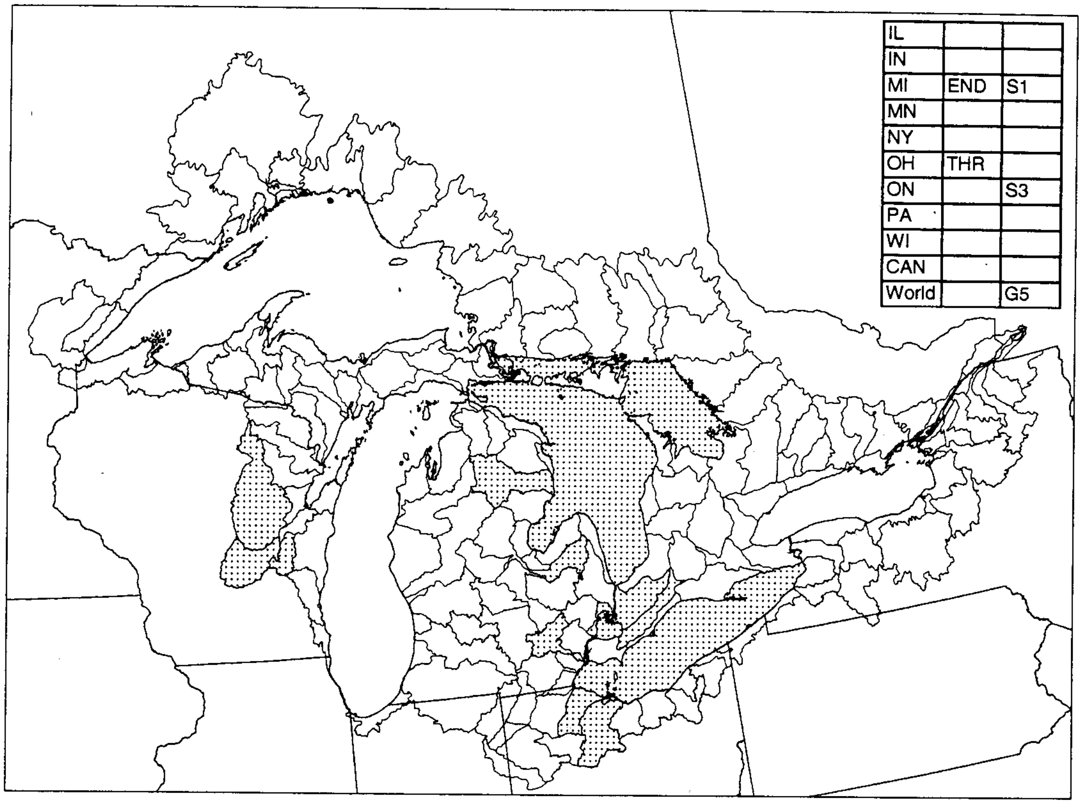

Distribution and conservation status of the Iowa darter, *Etheostoma exile*, in the Great Lakes basin.



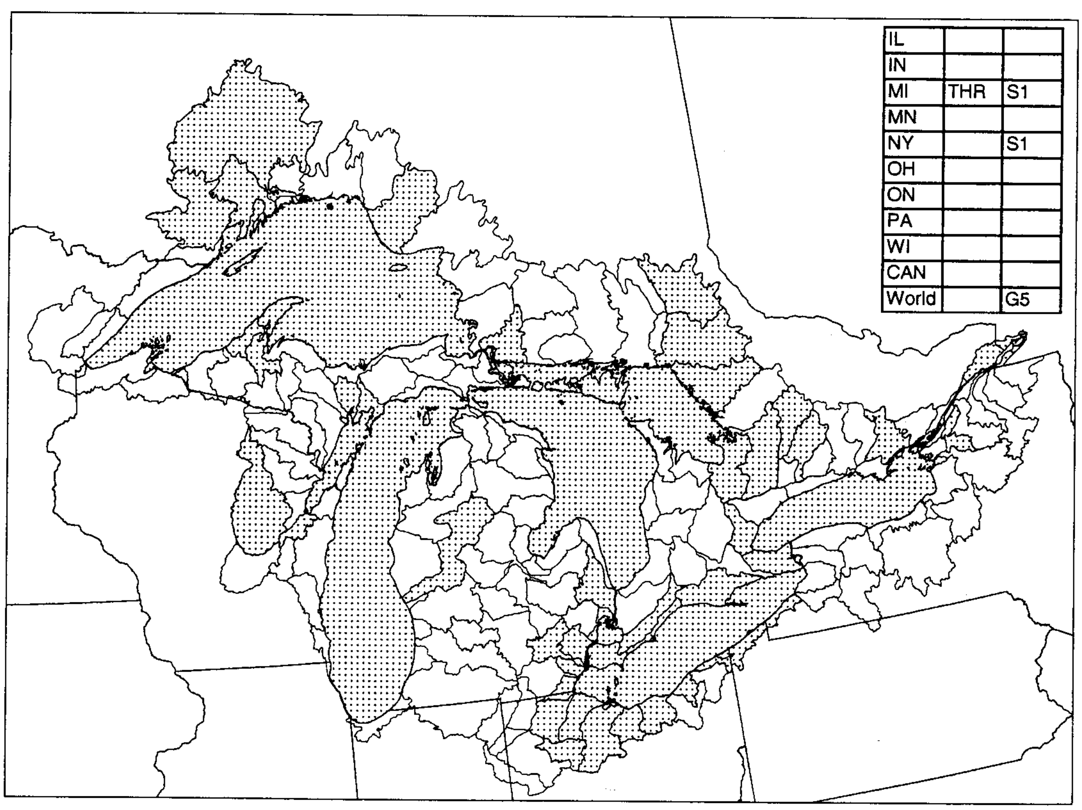

Distribution and conservation status of the least darter, *Etheostoma microperca*, in the Great Lakes basin.



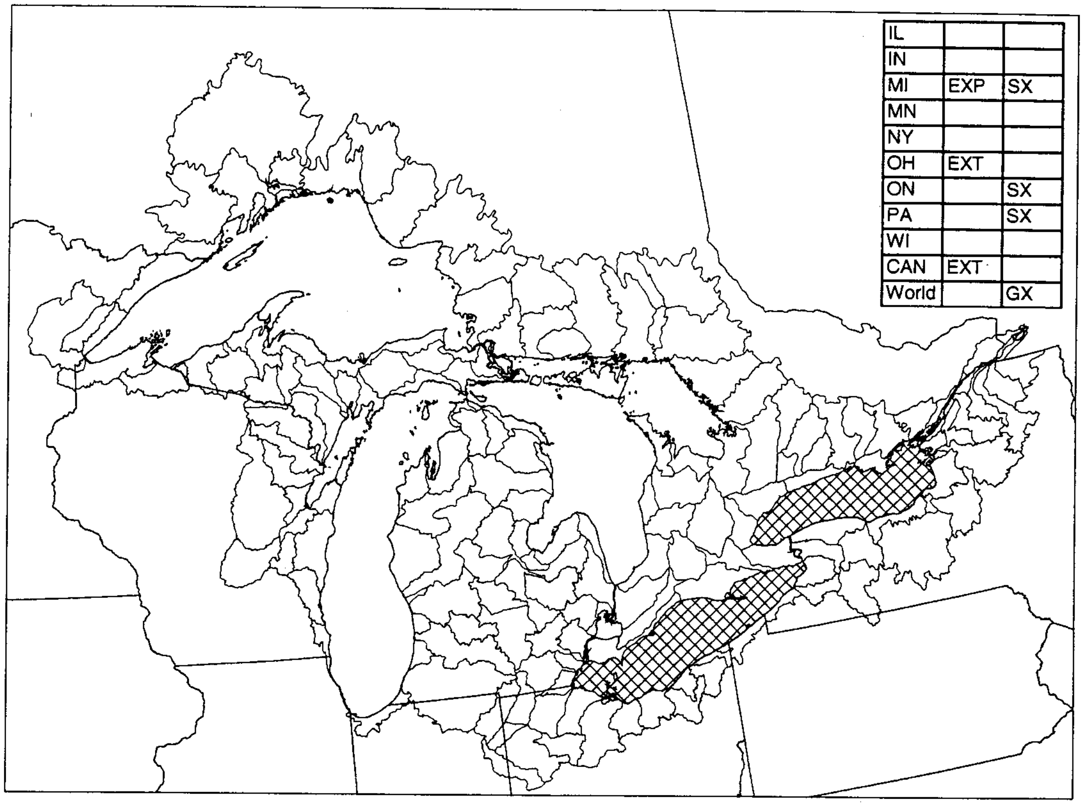

Distribution and conservation status of the channel darter, *Percina copelandi*, in the Great Lakes basin.




Distribution and conservation status of the river darter, *Percina shumardi*, in the Great Lakes basin.




Distribution and conservation status of the sauger, *Stizostedion canadense*, in the Great Lakes basin.




Distribution and conservation status of the blue pike, *Stizostedion vitreum glaucum*, in the Great Lakes basin. Stipple- native; crosshaching- extirpated.

Appendix D. Frequency of occurrence of categories for categorical variables. Frequencies of categories (1 = low preference, 2 = medium preference, 3 = high preference, 4 = no preference) for adult and juvenile feeding and habitat and spawning variables given for species at-risk and not at-risk.

| | Species At-Risk | | | | Species Not At-Risk | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| BO | 58 | 5 | 1 | 16 | 65 | 5 | 2 | 14 |
| PE | 32 | 12 | 2 | 34 | 37 | 9 | 3 | 37 |
| SU | 15 | 4 | 1 | 60 | 14 | 7 | 3 | 62 |
| NO | 2 | 0 | 0 | 78 | 0 | 0 | 0 | 86 |
| FI | 1 | 2 | 2 | 75 | 2 | 0 | 0 | 84 |
| GR | 60 | 3 | 0 | 17 | 59 | 2 | 5 | 20 |
| SO | 7 | 1 | 0 | 72 | 14 | 0 | 1 | 71 |
| ST | 4 | 0 | 1 | 75 | 4 | 1 | 0 | 81 |
| PU | 22 | 13 | 4 | 41 | 26 | 17 | 7 | 36 |
| AM | 4 | 0 | 0 | 76 | 7 | 2 | 0 | 77 |
| PH | 2 | 1 | 3 | 74 | 5 | 6 | 4 | 71 |
| MA | 9 | 6 | 10 | 55 | 12 | 6 | 18 | 50 |
| CR | 44 | 15 | 7 | 14 | 44 | 22 | 7 | 13 |
| AN | 4 | 1 | 4 | 71 | 6 | 6 | 4 | 70 |
| MO | 11 | 6 | 11 | 52 | 11 | 12 | 5 | 58 |
| IN | 49 | 9 | 6 | 16 | 65 | 12 | 2 | 7 |
| FI2 | 11 | 2 | 11 | 56 | 17 | 6 | 18 | 45 |
| PA | 2 | 0 | 0 | 78 | 0 | 0 | 0 | 86 |
| OT | 1 | 1 | 10 | 68 | 2 | 5 | 6 | 73 |
| VEGETANS | 1 | 0 | 17 | 62 | 0 | 1 | 20 | 65 |
| ALGAES | 0 | 0 | 2 | 75 | 0 | 0 | 3 | 83 |
| WOODS | 0 | 1 | 7 | 72 | 0 | 0 | 16 | 70 |
| SUBSTRTS | 1 | 1 | 18 | 60 | 0 | 0 | 23 | 63 |
| OVERHEDS | 0 | 1 | 5 | 74 | 0 | 1 | 10 | 75 |
| DEPTH1 | 0 | 1 | 16 | 63 | 0 | 4 | 24 | 58 |
| DEPTH2 | 0 | 3 | 31 | 46 | 0 | 6 | 33 | 47 |
| DEPTH3 | 0 | 3 | 14 | 63 | 0 | 0 | 29 | 57 |
| DEPTH4 | 0 | 1 | 9 | 70 | 0 | 1 | 11 | 74 |
| DEPTH5 | 0 | 0 | 16 | 64 | 0 | 0 | 6 | 80 |
| POOLS | 0 | 1 | 46 | 33 | 0 | 1 | 56 | 29 |
| RIFFLES | 0 | 3 | 22 | 55 | 2 | 1 | 24 | 59 |
| RUNS | 0 | 0 | 13 | 67 | 0 | 2 | 18 | 66 |
| RAPIDS | 0 | 1 | 1 | 78 | 0 | 0 | 3 | 83 |
| BEDRKS | 0 | 0 | 4 | 76 | 0 | 0 | 1 | 85 |
| BOULDER | 0 | 0 | 7 | 73 | 0 | 1 | 2 | 83 |
| COBBLE | 0 | 0 | 11 | 69 | 0 | 1 | 4 | 81 |
| RUBBLE | 0 | 0 | 14 | 66 | 0 | 2 | 21 | 63 |

*Appx. D cont.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GRAVEL | 0 | 0 | 40 | 40 | 0 | 1 | 50 | 35 |
| SAND | 0 | 2 | 20 | 58 | 0 | 1 | 39 | 46 |
| SILT_CLA | 0 | 2 | 15 | 63 | 0 | 1 | 13 | 72 |
| HARD_PAN | 0 | 0 | 1 | 79 | 0 | 0 | 0 | 86 |
| DETRITUS | 0 | 0 | 3 | 77 | 0 | 0 | 6 | 80 |
| VEGETANA | 0 | 5 | 25 | 50 | 2 | 6 | 37 | 41 |
| ALGAEA | 0 | 0 | 4 | 76 | 0 | 1 | 3 | 82 |
| WOODA | 0 | 3 | 6 | 71 | 0 | 1 | 20 | 65 |
| SUBSTRTA | 0 | 1 | 18 | 61 | 0 | 1 | 22 | 63 |
| OVERHEDA | 0 | 0 | 3 | 77 | 0 | 0 | 9 | 77 |
| POOLA | 1 | 1 | 64 | 14 | 2 | 1 | 75 | 8 |
| RIFFLEA | 3 | 4 | 20 | 53 | 3 | 4 | 23 | 56 |
| RUNA | 2 | 8 | 16 | 54 | 3 | 12 | 25 | 46 |
| RAPIDA | 0 | 0 | 1 | 79 | 0 | 0 | 3 | 83 |

Frequencies of categories (1 = low preference, 2 = medium preference, 3 = high preference, 4 = no preference) for turbidity tolerance variable (TURBIDYA) given for species at-risk and not at-risk.

| TURBIDYA | | | |
|---|---|---|---|
| SAR | | SNAR | |
| 0 | 39 | 0 | 27 |
| 1 | 6 | 1 | 14 |
| 2 | 17 | 2 | 24 |
| 3 | 0 | 3 | 2 |
| 4 | 18 | 4 | 17 |

Frequencies of categories (0 = none, 1 =bait, 2 = aboriginal, 3 = aesthetic, 4 = commercial, 5 = recreational) for human value variable (VALUE) given for species at-risk and not at-risk.

| VALUE | | | |
|---|---|---|---|
| SAR | | SNAR | |
| 0 | 37 | 0 | 36 |
| 1 | 15 | 1 | 23 |
| 2 | 0 | 2 | 0 |
| 3 | 1 | 3 | 0 |
| 4 | 18 | 4 | 12 |
| 5 | 9 | 5 | 15 |

Frequencies of categories (1 =low preference, 2 = medium preference, 3 = high preference) for two adult and juvenile habitat variables (LAKE, STREAM) given for species at-risk and not at-risk.

| | Species At Risk | | | Species Not At Risk | | |
|---|---|---|---|---|---|---|
| Variables | 1 | 2 | 3 | 1 | 2 | 3 |
| LAKE | 51 | 8 | 21 | 57 | 12 | 17 |
| STREAM | 67 | 4 | 9 | 83 | 3 | 0 |

Frequencies of categories for spawning behavior categories (Balon, 1975, 1981) variable (BALON_GUILD) given for species at-risk and not at-risk.

| BALON_GUILD | | | |
|---|---|---|---|
| SAR | | SNAR | |
| 1 | 7 | 1 | 2 |
| 2 | 7 | 2 | 2 |
| 3 | 15 | 3 | 16 |
| 4 | 1 | 4 | 10 |
| 5 | 14 | 5 | 9 |
| 6 | 2 | 6 | 5 |
| 7 | 11 | 7 | 9 |
| 8 | 0 | 8 | 0 |
| 9 | 1 | 9 | 0 |
| 10 | 0 | 10 | 2 |
| 11 | 8 | 11 | 7 |
| 12 | 0 | 12 | 4 |
| 13 | 1 | 13 | 3 |
| 14 | 1 | 14 | 13 |
| ? | 1 | ? | 1 |

Appendix E. Kolmogorov-Smirnov and Shapiro-Wilk normality test results.

Results for the Kolmogorov-Smirnov and Shapiro-Wilk normality tests for categorical variables for Great Lakes basin fishes.

| Variables | K-S (d) $p < 0.01$ | S-W (w) $p < 0.01$ | n | MIN | MAX |
|---|---|---|---|---|---|
| LAKE | 0.4023 | 0.6480 | 166 | 1 | 3 |
| STREAM | 0.5213 | 0.3544 | 166 | 1 | 3 |
| VALUE | 0.3022 | 0.7449 | 166 | 0 | 5 |
| BALON_GUILD | 0.2781 | 0.3548 | 163 | 1 | 100 |
| BO | 0.4514 | 0.5498 | 169 | 1 | 4 |
| PE | 0.2906 | 0.7165 | 166 | 1 | 4 |
| SU | 0.4544 | 0.5702 | 166 | 1 | 4 |
| NO | 0.5316 | 0.0836 | 166 | 1 | 4 |
| FI | 0.5350 | 0.1900 | 166 | 1 | 4 |
| GR | 0.4430 | 0.5791 | 166 | 1 | 4 |
| SO | 0.5135 | 0.4143 | 166 | 1 | 4 |
| ST | 0.5368 | 0.2459 | 166 | 1 | 4 |
| PU | 0.3008 | 0.7547 | 166 | 1 | 4 |
| AM | 0.5354 | 0.2951 | 166 | 1 | 4 |
| PH | 0.5104 | 0.3845 | 166 | 1 | 4 |
| MA | 0.3797 | 0.6619 | 166 | 1 | 4 |
| CR | 0.3187 | 0.7308 | 166 | 1 | 4 |
| AN | 0.4930 | 0.4509 | 166 | 1 | 4 |
| MO | 0.3964 | 0.6597 | 166 | 1 | 4 |
| IN | 0.4098 | 0.6144 | 166 | 1 | 4 |
| FI2 | 0.3595 | 0.6789 | 166 | 1 | 4 |
| PA | 0.5316 | 0.0836 | 166 | 1 | 4 |
| OT | 0.4919 | 0.4453 | 166 | 1 | 4 |
| VEGETANS | 0.4650 | 0.5311 | 166 | 1 | 4 |
| ALGAES | 0.5406 | 0.2165 | 166 | 3 | 4 |
| WOODS | 0.5124 | 0.4243 | 166 | 2 | 4 |
| SUBSTRTS | 0.4508 | 0.5607 | 166 | 1 | 4 |
| OVERHEDS | 0.5246 | 0.3487 | 166 | 2 | 4 |
| DEPTH1 | 0.4466 | 0.5909 | 166 | 2 | 4 |
| DEPTH2 | 0.3561 | 0.7085 | 166 | 2 | 4 |
| DEPTH3 | 0.4451 | 0.5940 | 166 | 2 | 4 |
| DEPTH4 | 0.5124 | 0.4159 | 166 | 2 | 4 |
| DEPTH5 | 0.5178 | 0.4052 | 166 | 3 | 4 |
| POOLS | 0.3925 | 0.6579 | 166 | 2 | 4 |
| RIFFLES | 0.4183 | 0.6123 | 166 | 1 | 4 |
| RUNS | 0.4878 | 0.5021 | 166 | 2 | 4 |
| RAPIDS | 0.5359 | 0.1555 | 166 | 2 | 4 |

| *Appx. E cont.* Variables | K-S (d) *p* < 0.01 | S-W (w) *p* < 0.0000 | n | MIN | MAX |
|---|---|---|---|---|---|
| BEDRCKS | 0.5395 | 0.1584 | 166 | 3 | 4 |
| BOULDER | 0.5351 | 0.2671 | 166 | 2 | 4 |
| COBBLE | 0.5284 | 0.3373 | 166 | 2 | 4 |
| RUBBLE | 0.4771 | 0.5297 | 166 | 2 | 4 |
| GRAVEL | 0.3551 | 0.6597 | 166 | 2 | 4 |
| SAND | 0.3959 | 0.6553 | 166 | 2 | 4 |
| SILT_CLA | 0.4886 | 0.4961 | 166 | 2 | 4 |
| HARD_PAN | 0.5316 | 0.0836 | 166 | 3 | 4 |
| DETRITUS | 0.5402 | 0.2335 | 166 | 3 | 4 |
| VEGETANA | 0.3386 | 0.7257 | 166 | 1 | 4 |
| ALGAEA | 0.5366 | 0.2340 | 166 | 2 | 4 |
| WOODA | 0.4924 | 0.4803 | 166 | 2 | 4 |
| SUBSTRTA | 0.4631 | 0.5599 | 166 | 2 | 4 |
| OVERHEDA | 0.5376 | 0.2794 | 166 | 3 | 4 |
| TURBIDYA | 0.2327 | 0.8104 | 166 | 0 | 4 |
| POOLA | 0.4420 | 0.5066 | 166 | 1 | 4 |
| RIFFLEA | 0.3869 | 0.6428 | 166 | 1 | 4 |
| RUNA | 0.3587 | 0.7134 | 166 | 1 | 4 |
| RAPIDA | 0.5380 | 0.1360 | 166 | 3 | 4 |

Results for Kolmogorov-Smirnov and Shapiro-Wilk normality tests for continuous variables.

| Variables | K-S (d) p < 0.01 | S-W (w) p < 0.01 | n | MEAN | MIN | MAX | SD |
|---|---|---|---|---|---|---|---|
| MAXAGE | 0.2896 | 0.4136 | 166 | 9.3102 | 1 | 154 | 14 |
| MAXLENGTH | 0.2270 | 0.6986 | 168 | 352.7173 | 46 | 2669 | 409 |
| REPROLEN | 0.2525 | 0.6086 | 161 | 178.8081 | 24 | 1900 | 231 |
| REPROAGE | 0.2595 | 0.5419 | 160 | 2.9312 | 1 | 27 | 2 |

Appendix F. Spearman's correlation matrices for independent variables.

Results for Spearman's correlation matrix of adult feeding variables for Great Lakes basin fishes. Significant correlations ($n$ = 166, $r \geq 0.154$, $p = 0.05$) are marked in bold.

| | BO | PE | SU | NO | FI | GR | SO | ST | PU | AM | PH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BO | 1 | **-0.424** | **-0.192** | **-0.224** | -0.117 | **0.452** | **0.207** | -0.147 | 0.041 | **-0.332** | -0.037 |
| PE | **-0.424** | 1 | **0.370** | -0.121 | **0.159** | -0.121 | **-0.241** | 0.103 | **0.301** | **0.193** | -0.055 |
| SU | **-0.192** | **0.370** | 1 | -0.064 | 0.053 | 0.011 | -0.101 | 0.151 | **0.341** | **0.177** | -0.053 |
| NO | **-0.224** | -0.121 | -0.064 | 1 | -0.022 | **-0.197** | -0.044 | -0.027 | -0.109 | -0.032 | -0.039 |
| FI | -0.117 | **0.159** | 0.053 | -0.022 | 1 | -0.099 | -0.077 | -0.048 | -0.074 | -0.056 | -0.032 |
| GR | **0.452** | -0.121 | 0.011 | **-0.197** | -0.099 | 1 | **-0.300** | -0.112 | 0.015 | **-0.347** | 0.065 |
| SO | **0.207** | **-0.241** | -0.101 | -0.044 | -0.077 | **-0.300** | 1 | -0.097 | **-0.300** | -0.114 | 0.060 |
| ST | -0.147 | 0.103 | 0.151 | -0.027 | -0.048 | -0.112 | -0.097 | 1 | -0.069 | **0.460** | -0.086 |
| PU | 0.041 | **0.301** | **0.341** | -0.109 | -0.074 | 0.015 | **-0.300** | -0.069 | 1 | -0.119 | **-0.205** |
| AM | **-0.332** | **0.193** | **0.177** | -0.032 | -0.056 | **-0.347** | -0.114 | **0.460** | -0.119 | 1 | -0.004 |
| PH | -0.037 | -0.055 | -0.053 | -0.039 | -0.032 | 0.065 | 0.060 | -0.086 | **-0.205** | -0.004 | 1 |
| MA | 0.149 | -0.102 | -0.025 | -0.072 | -0.128 | 0.137 | **0.189** | -0.118 | **-0.157** | -0.123 | **0.329** |
| CR | **0.254** | 0.102 | 0.020 | **-0.209** | 0.095 | **0.228** | 0.022 | -0.010 | -0.004 | **-0.185** | -0.097 |
| AN | **0.212** | -0.035 | 0.085 | -0.043 | -0.075 | 0.032 | 0.025 | 0.062 | 0.111 | 0.119 | 0.029 |
| MO | **0.326** | **-0.187** | -0.066 | -0.071 | -0.114 | 0.085 | 0.120 | -0.084 | -0.003 | -0.094 | -0.127 |
| IN | **0.401** | -0.116 | **0.209** | **-0.242** | -0.090 | **0.238** | 0.151 | **-0.184** | **0.271** | **-0.242** | **-0.156** |
| FI2 | **-0.154** | **0.396** | **0.185** | -0.076 | 0.004 | -0.140 | -0.113 | **0.290** | **0.276** | **0.340** | **-0.203** |
| PA | **-0.224** | 0.117 | -0.064 | -0.012 | -0.022 | **-0.197** | -0.044 | -0.027 | 0.144 | -0.032 | -0.039 |
| OT | -0.125 | **0.185** | **0.170** | -0.041 | -0.073 | -0.064 | -0.098 | **0.337** | -0.015 | **0.233** | 0.037 |

| | MA | CR | AN | MO | IN | FI2 | PA | OT |
|---|---|---|---|---|---|---|---|---|
| BO | 0.149 | **0.254** | **0.212** | **0.326** | **0.401** | **-0.154** | **-0.224** | -0.125 |
| PE | -0.102 | 0.102 | -0.035 | **-0.187** | -0.116 | **0.396** | 0.117 | **0.185** |
| SU | -0.025 | 0.020 | 0.085 | -0.066 | **0.209** | **0.185** | -0.064 | **0.170** |
| NO | -0.072 | **-0.209** | -0.043 | -0.071 | **-0.242** | -0.076 | -0.012 | -0.041 |
| FI | -0.128 | 0.095 | -0.075 | -0.114 | -0.090 | 0.004 | -0.022 | -0.073 |
| GR | 0.137 | **0.228** | 0.032 | 0.085 | **0.238** | -0.140 | **-0.197** | -0.064 |
| SO | **0.189** | 0.022 | 0.025 | 0.120 | 0.151 | -0.113 | -0.044 | -0.098 |
| ST | -0.118 | -0.010 | 0.062 | -0.084 | **-0.184** | **0.290** | -0.027 | **0.337** |
| PU | **-0.157** | -0.004 | 0.111 | -0.003 | **0.271** | **0.276** | 0.144 | -0.015 |
| AM | -0.123 | **-0.185** | 0.119 | -0.094 | **-0.242** | **0.340** | -0.032 | **0.233** |
| PH | **0.329** | -0.097 | 0.029 | -0.127 | **-0.156** | **-0.203** | -0.039 | 0.037 |
| MA | 1 | -0.071 | 0.077 | -0.025 | -0.056 | **-0.188** | -0.072 | 0.013 |
| CR | -0.071 | 1 | 0.118 | **0.184** | **0.344** | 0.093 | **-0.209** | **-0.249** |
| AN | 0.077 | 0.118 | 1 | **0.329** | **0.222** | **0.154** | -0.043 | 0.042 |
| MO | -0.025 | **0.184** | **0.329** | 1 | **0.174** | 0.098 | -0.071 | -0.058 |
| IN | -0.056 | **0.344** | **0.222** | **0.174** | 1 | -0.043 | **-0.242** | **-0.258** |
| FI2 | **-0.188** | 0.093 | **0.154** | 0.098 | -0.043 | 1 | -0.076 | **0.199** |
| PA | -0.072 | **-0.209** | -0.043 | -0.071 | **-0.242** | -0.076 | 1 | -0.041 |
| OT | 0.013 | **-0.249** | 0.042 | -0.058 | **-0.258** | **0.199** | -0.041 | 1 |

Results for Spearman's correlation matrix of adult habitat variables for Great Lakes basin fishes. Significant correlations ($n = 166$, $r = 0.152$, $p = 0.05$) are marked in bold.

| | LAKE | STREAM | VEGETANA | ALGAEA | WOODA | SUBSTRTA |
|---|---|---|---|---|---|---|
| LAKE | 1 | **-0.155** | **0.193** | 0.034 | **0.167** | **-0.193** |
| STREAM | **-0.155** | 1 | **0.176** | 0.067 | 0.138 | 0.149 |
| VEGETANA | **0.193** | **0.176** | 1 | **0.253** | 0.089 | -0.150 |
| ALGAEA | 0.034 | 0.067 | **0.253** | 1 | -0.096 | -0.071 |
| WOODA | **0.167** | 0.138 | 0.089 | -0.096 | 1 | **0.252** |
| SUBSTRTA | **-0.193** | 0.149 | -0.150 | -0.071 | **0.252** | 1 |
| OVERHEDA | -0.002 | 0.086 | **-0.156** | -0.060 | **0.331** | **0.289** |
| TURBIDYA | -0.149 | -0.018 | -0.019 | -0.019 | -0.017 | 0.011 |
| POOLA | -0.049 | 0.078 | 0.129 | -0.013 | -0.004 | -0.064 |
| RIFFLEA | **-0.196** | **0.192** | -0.045 | -0.101 | 0.004 | 0.148 |
| RUNA | 0.057 | **0.189** | 0.032 | -0.035 | 0.070 | 0.025 |
| RAPIDA | -0.126 | 0.049 | -0.127 | -0.034 | -0.070 | 0.079 |

| | OVERHEDA | TURBIDYA | POOLA | RIFFLEA | RUNA | RAPIDA |
|---|---|---|---|---|---|---|
| LAKE | -0.002 | -0.149 | -0.049 | **-0.196** | 0.057 | -0.126 |
| STREAM | 0.086 | -0.018 | 0.078 | **0.192** | **0.189** | 0.049 |
| VEGETANA | **-0.156** | -0.019 | 0.129 | -0.045 | 0.032 | -0.127 |
| ALGAEA | -0.060 | -0.019 | -0.013 | -0.101 | -0.035 | -0.034 |
| WOODA | **0.331** | -0.017 | -0.004 | 0.004 | 0.070 | -0.070 |
| SUBSTRTA | **0.289** | 0.011 | -0.064 | 0.148 | 0.025 | 0.079 |
| OVERHEDA | 1 | 0.005 | 0.051 | **0.169** | **0.173** | -0.044 |
| TURBIDYA | 0.005 | 1 | 0.151 | -0.069 | -0.001 | 0.003 |
| POOLA | 0.051 | 0.151 | 1 | 0.079 | **0.163** | 0.115 |
| RIFFLEA | **0.169** | -0.069 | 0.079 | 1 | **0.231** | 0.112 |
| RUNA | **0.173** | -0.001 | **0.163** | **0.231** | 1 | -0.015 |
| RAPIDA | -0.044 | 0.003 | 0.115 | 0.112 | -0.015 | 1 |

Results for Spearman's correlation matrix of spawning depth and flow regime variables for Great Lakes basin fishes. Significant correlations ($n = 166$, $r = 0.152$, $p = 0.05$) are marked in bold.

| | DEPTH1 | DEPTH2 | DEPTH3 | DEPTH4 | DEPTH5 |
|---|---|---|---|---|---|
| DEPTH1 | 1 | **0.509** | **0.193** | 0.083 | -0.124 |
| DEPTH2 | **0.509** | 1 | **0.403** | **0.187** | **-0.174** |
| DEPTH3 | **0.193** | **0.403** | 1 | **0.410** | 0.054 |
| DEPTH4 | 0.083 | **0.187** | **0.410** | 1 | **0.361** |
| DEPTH5 | -0.124 | **-0.174** | 0.054 | **0.361** | 1 |
| POOLS | 0.025 | 0.073 | 0.114 | 0.052 | 0.139 |
| RIFFLES | -0.001 | 0.023 | -0.056 | -0.124 | **-0.208** |
| RUNS | 0.065 | 0.086 | -0.093 | -0.038 | -0.067 |
| RAPIDS | -0.097 | -0.045 | 0.069 | 0.082 | 0.099 |

| | POOLS | RIFFLES | RUNS | RAPIDS |
|---|---|---|---|---|
| DEPTH1 | 0.025 | -0.001 | 0.065 | -0.097 |
| DEPTH2 | 0.073 | 0.023 | 0.086 | -0.045 |
| DEPTH3 | 0.114 | -0.056 | -0.093 | 0.069 |
| DEPTH4 | 0.052 | -0.124 | -0.038 | 0.082 |
| DEPTH5 | 0.139 | **-0.208** | -0.067 | 0.099 |
| POOLS | 1 | **-0.208** | 0.045 | -0.101 |
| RIFFLES | **-0.208** | 1 | 0.055 | **0.180** |
| RUNS | 0.045 | 0.055 | 1 | 0.047 |
| RAPIDS | -0.101 | **0.180** | 0.047 | 1 |

Results for Spearman's correlation matrix of spawning behavior and habitat variables for Great Lakes basin fishes. Significant correlations ($n = 161$, $r = 0.154$, $p = 0.05$) are marked in bold.

| | BALON_GD | VEGETANS | ALGAES | WOODS | SUBSTRTS |
|---|---|---|---|---|---|
| BALON_GD | 1 | 0.003 | 0.033 | -0.091 | -0.069 |
| VEGETANS | 0.003 | 1 | **0.200** | **0.189** | -0.043 |
| ALGAES | 0.033 | **0.200** | 1 | -0.007 | -0.060 |
| WOODS | -0.091 | **0.189** | -0.007 | 1 | **0.288** |
| SUBSTRTS | -0.069 | -0.043 | -0.060 | **0.288** | 1 |
| OVERHEDS | -0.092 | 0.041 | -0.070 | **0.185** | 0.054 |
| BEDRKS | -0.007 | -0.093 | 0.137 | -0.073 | 0.112 |
| BOULDER | 0.025 | -0.129 | 0.058 | -0.102 | **0.172** |
| COBBLE | 0.057 | -0.129 | 0.024 | -0.132 | **0.156** |
| RUBBLE | 0.109 | **-0.165** | -0.046 | **-0.182** | -0.004 |
| GRAVEL | 0.127 | **-0.204** | -0.117 | **-0.166** | 0.024 |
| SAND | 0.030 | 0.011 | -0.048 | 0.059 | -0.060 |
| SILT_CLA | 0.011 | 0.122 | 0.035 | 0.026 | 0.008 |
| HARD_PAN | -0.010 | 0.120 | -0.017 | -0.032 | -0.045 |
| DETRITUS | -0.024 | **0.315** | 0.081 | 0.114 | 0.023 |

| | OVERHEDS | BEDRKS | BOULDER | COBBLE | RUBBLE | GRAVEL |
|---|---|---|---|---|---|---|
| BALON_GD | -0.092 | -0.007 | 0.025 | 0.057 | 0.109 | 0.127 |
| VEGETANS | 0.041 | -0.093 | -0.129 | -0.129 | **-0.165** | **-0.204** |
| ALGAES | -0.070 | 0.137 | 0.058 | 0.024 | -0.046 | -0.117 |
| WOODS | **0.185** | -0.073 | -0.102 | -0.132 | **-0.182** | **-0.166** |
| SUBSTRTS | 0.054 | 0.112 | **0.172** | **0.156** | -0.004 | 0.024 |
| OVERHEDS | 1 | -0.059 | -0.019 | -0.106 | -0.099 | -0.025 |
| BEDRKS | -0.059 | 1 | **0.345** | **0.271** | 0.140 | 0.083 |
| BOULDER | -0.019 | **0.345** | 1 | **0.678** | **0.214** | **0.168** |
| COBBLE | -0.106 | **0.271** | **0.678** | 1 | **0.411** | **0.202** |
| RUBBLE | -0.099 | 0.140 | 0.214 | **0.411** | 1 | **0.267** |
| GRAVEL | -0.025 | 0.083 | **0.168** | **0.202** | **0.267** | 1 |
| SAND | 0.076 | -0.001 | 0.024 | 0.005 | 0.007 | **0.238** |
| SILT_CLA | 0.153 | -0.004 | -0.066 | -0.151 | **-0.158** | -0.087 |
| HARD_PAN | **0.194** | -0.014 | -0.020 | -0.026 | -0.042 | -0.088 |
| DETRITUS | -0.080 | -0.044 | -0.060 | -0.079 | -0.070 | -0.005 |

| | SAND | SILT_CLA | HARD_PAN | DETRITUS |
|---|---|---|---|---|
| BALON_GD | 0.030 | 0.011 | -0.010 | -0.024 |
| VEGETANS | 0.011 | 0.122 | 0.120 | **0.315** |
| ALGAES | -0.048 | 0.035 | -0.017 | 0.081 |
| WOODS | 0.059 | 0.026 | -0.032 | 0.114 |
| SUBSTRTS | -0.060 | 0.008 | -0.045 | 0.023 |
| OVERHEDS | 0.076 | 0.153 | **0.194** | -0.080 |
| BEDRKS | -0.001 | -0.004 | -0.014 | -0.044 |
| BOULDER | 0.024 | -0.066 | -0.020 | -0.060 |
| COBBLE | 0.005 | -0.151 | -0.026 | -0.079 |
| RUBBLE | 0.007 | **-0.158** | -0.042 | -0.070 |
| GRAVEL | **0.238** | -0.087 | -0.088 | -0.005 |
| SAND | 1 | **0.346** | 0.089 | 0.121 |
| SILT_CLA | **0.346** | 1 | 0.138 | **0.425** |
| HARD_PAN | 0.089 | 0.138 | 1 | -0.019 |
| DETRITUS | 0.121 | **0.425** | -0.019 | 1 |

Results of Spearman's correlations for continuous variables for Great Lakes basin fishes. Significant correlations ($n$ = 156, $r$ = 0.157, $p$ = 0.05) are marked in bold.

| | MAXAGE | MAXLENGT | REPRLEN | REPRAGE |
|---|---|---|---|---|
| MAXAGE | 1 | **0.768** | **0.621** | **0.824** |
| MAXLENGT | **0.768** | 1 | **0.908** | **0.787** |
| REPRLEN | **0.621** | **0.908** | 1 | **0.719** |
| REPRAGE | **0.824** | **0.787** | **0.719** | 1 |

Appendix G. Results for Mann-Whitney test for significance between variables with STATUS1 (0 = not at-risk, 1 = at-risk) as grouping variable. Significant variables (*p*-adjusted $\leq 0.05$) are marked with an asterisk (*).

| Variable | U | Z | *p*-level | Z adjusted | *p*-level adjusted | Valid N Group 1 | Valid N Group 2 |
|---|---|---|---|---|---|---|---|
| MAXAGEL | 3016 | -0.993 | 0.321 | -1.002 | 0.316 | 85 | 78 |
| MAXLENL | 2910 | -1.589 | 0.112 | -1.589 | 0.112 | 86 | 79 |
| LAKE | 3295 | -0.469 | 0.639 | -0.556 | 0.578 | 86 | 80 |
| *STREAM | 2988 | -1.462 | 0.144 | -2.857 | 0.004 | 86 | 80 |
| VALUE | 3314 | 0.407 | 0.684 | 0.431 | 0.667 | 86 | 80 |
| *BALON_GU | 2456 | 2.643 | 0.008 | 2.664 | 0.008 | 83 | 78 |
| *REPLENL | 2543 | -2.189 | 0.029 | -2.189 | 0.029 | 86 | 74 |
| *REPAGEL | 2438 | -2.319 | 0.020 | -2.386 | 0.017 | 85 | 73 |
| BO | 3323 | -0.380 | 0.704 | -0.496 | 0.620 | 86 | 80 |
| PE | 3400 | -0.129 | 0.897 | -0.140 | 0.888 | 86 | 80 |
| SU | 3383 | -0.186 | 0.853 | -0.240 | 0.810 | 86 | 80 |
| NO | 3354 | 0.278 | 0.781 | 1.471 | 0.141 | 86 | 80 |
| FI | 3309 | 0.423 | 0.672 | 1.216 | 0.224 | 86 | 80 |
| GR | 3242 | 0.640 | 0.522 | 0.812 | 0.417 | 86 | 80 |
| SO | 3181 | -0.837 | 0.403 | -1.398 | 0.162 | 86 | 80 |
| ST | 3426 | 0.047 | 0.963 | 0.114 | 0.909 | 86 | 80 |
| PU | 3172 | -0.868 | 0.386 | -0.930 | 0.352 | 86 | 80 |
| AM | 3256 | -0.595 | 0.552 | -1.277 | 0.202 | 86 | 80 |
| PH | 3091 | -1.128 | 0.259 | -1.954 | 0.051 | 86 | 80 |
| MA | 3111 | -1.063 | 0.288 | -1.236 | 0.216 | 86 | 80 |
| CR | 3393 | 0.154 | 0.878 | 0.168 | 0.867 | 86 | 80 |
| AN | 3182 | -0.834 | 0.404 | -1.341 | 0.180 | 86 | 80 |
| MO | 3407 | 0.107 | 0.915 | 0.127 | 0.899 | 86 | 80 |
| *IN | 2861 | -1.873 | 0.061 | -2.286 | 0.022 | 86 | 80 |
| *FI2 | 2839 | -1.944 | 0.052 | -2.223 | 0.026 | 86 | 80 |
| PA | 3354 | 0.278 | 0.781 | 1.471 | 0.141 | 86 | 80 |
| OT | 3409 | -0.102 | 0.919 | -0.164 | 0.870 | 86 | 80 |
| VEGETANS | 3376 | -0.207 | 0.836 | -0.281 | 0.779 | 86 | 80 |
| ALGAES | 3345 | 0.307 | 0.759 | 0.828 | 0.408 | 86 | 80 |
| WOODS | 3152 | -0.931 | 0.352 | -1.527 | 0.127 | 86 | 80 |
| SUBSTRTS | 3403 | -0.120 | 0.905 | -0.157 | 0.875 | 86 | 80 |
| OVERHEDS | 3261 | -0.580 | 0.562 | -1.104 | 0.270 | 86 | 80 |

*Appx. G cont.*

| Variables | U | Z | *p*-level | Z adjusted | *p*-level adjusted | Valid N Group 1 | Valid N Group 2 |
|---|---|---|---|---|---|---|---|
| DEPTH1 | 3031 | -1.322 | 0.186 | -1.708 | 0.088 | 86 | 80 |
| DEPTH2 | 3299 | -0.457 | 0.647 | -0.522 | 0.602 | 86 | 80 |
| DEPTH3 | 3055 | -1.246 | 0.213 | -1.602 | 0.109 | 86 | 80 |
| DEPTH4 | 3391 | -0.158 | 0.874 | -0.269 | 0.788 | 86 | 80 |
| *DEPTH5 | 2992 | 1.448 | 0.148 | 2.465 | 0.014 | 86 | 80 |
| POOLS | 3186 | -0.821 | 0.412 | -0.970 | 0.332 | 86 | 80 |
| RIFFLES | 3435 | -0.016 | 0.987 | -0.020 | 0.984 | 86 | 80 |
| RUNS | 3186 | -0.821 | 0.412 | -1.186 | 0.236 | 86 | 80 |
| RAPIDS | 3408 | -0.105 | 0.916 | -0.355 | 0.723 | 86 | 80 |
| BEDRKS | 3308 | 0.427 | 0.670 | 1.441 | 0.150 | 86 | 80 |
| BOULDER | 3263 | 0.574 | 0.566 | 1.392 | 0.164 | 86 | 80 |
| COBBLE | 3173 | 0.864 | 0.387 | 1.691 | 0.091 | 86 | 80 |
| RUBBLE | 3108 | -1.073 | 0.283 | -1.486 | 0.137 | 86 | 80 |
| GRAVEL | 3100 | -1.099 | 0.272 | -1.270 | 0.204 | 86 | 80 |
| *SAND | 2815 | -2.020 | 0.043 | -2.398 | 0.016 | 86 | 80 |
| SILT_CLA | 3264 | 0.570 | 0.568 | 0.843 | 0.399 | 86 | 80 |
| HARD_PAN | 3397 | 0.139 | 0.889 | 1.037 | 0.300 | 86 | 80 |
| DETRITUS | 3329 | -0.359 | 0.720 | -0.915 | 0.360 | 86 | 80 |
| VEGETANA | 2918 | -1.689 | 0.091 | -1.908 | 0.056 | 86 | 80 |
| ALGAEA | 3430 | 0.032 | 0.974 | 0.087 | 0.931 | 86 | 80 |
| *WOODA | 3014 | -1.377 | 0.169 | -2.061 | 0.039 | 86 | 80 |
| SUBSTRTA | 3339 | -0.326 | 0.744 | -0.433 | 0.665 | 86 | 80 |
| OVERHEDA | 3209 | -0.747 | 0.455 | -1.664 | 0.096 | 86 | 80 |
| TURBIDYA | 3027 | 1.336 | 0.181 | 1.400 | 0.161 | 86 | 80 |
| POOLA | 3137 | -0.981 | 0.327 | -1.531 | 0.126 | 86 | 80 |
| RIFFLEA | 3412 | -0.092 | 0.927 | -0.110 | 0.912 | 86 | 80 |
| RUNA | 2963 | -1.542 | 0.123 | -1.763 | 0.078 | 86 | 80 |
| RAPIDA | 3363 | -0.249 | 0.803 | -0.937 | 0.349 | 86 | 80 |

Appendix H. Results of the Kruskal-Wallis nonparametric ANOVA for significance between variables with STATUS3 (highest conservation ranking) as the grouping variable. Significant variables ($p \leq 0.05$) are marked with an asterisk (*).

| Variable | N | H | *p* | Median |
|---|---|---|---|---|
| LAKE | 166 | 0.985 | 0.912 | 1 |
| *STREAM | 166 | 34.133 | 0.000 | 1 |
| VALUE | 166 | 7.938 | 0.094 | 1 |
| *BALON_GUILD | 161 | 13.778 | 0.008 | 5 |
| BO | 166 | 7.979 | 0.092 | 1 |
| PE | 166 | 2.955 | 0.565 | 2 |
| SU | 166 | 4.792 | 0.309 | 4 |
| NO | 166 | 5.537 | 0.253 | 4 |
| FI | 166 | 9.098 | 0.059 | 4 |
| GR | 166 | 2.620 | 0.623 | 1 |
| SO | 166 | 3.161 | 0.531 | 4 |
| ST | 166 | 1.209 | 0.877 | 4 |
| PU | 166 | 3.803 | 0.433 | 3 |
| AM | 166 | 2.129 | 0.712 | 4 |
| PH | 166 | 4.911 | 0.297 | 4 |
| MA | 166 | 4.037 | 0.401 | 4 |
| CR | 166 | 0.886 | 0.927 | 1 |
| AN | 166 | 3.206 | 0.524 | 4 |
| MO | 166 | 0.855 | 0.931 | 4 |
| *IN | 166 | 22.750 | 0.000 | 1 |
| FI2 | 166 | 6.009 | 0.199 | 4 |
| *PA | 166 | 17.637 | 0.002 | 4 |
| OT | 166 | 1.330 | 0.856 | 4 |
| VEGETANS | 166 | 7.908 | 0.095 | 4 |
| ALGAES | 166 | 5.386 | 0.250 | 4 |
| WOODS | 166 | 6.339 | 0.175 | 4 |
| SUBSTRTS | 166 | 3.518 | 4.752 | 4 |
| OVERHEDS | 166 | 4.141 | 0.387 | 4 |
| DEPTH1 | 166 | 6.475 | 0.166 | 4 |
| DEPTH2 | 166 | 5.045 | 0.283 | 4 |
| DEPTH3 | 166 | 4.673 | 0.323 | 4 |
| DEPTH4 | 166 | 0.265 | 0.992 | 4 |
| DEPTH5 | 166 | 8.544 | 0.074 | 4 |

| *Appx. H cont.* Variables | N | H | *p* | Median |
|---|---|---|---|---|
| POOLS | 166 | 4.941 | 0.293 | 3 |
| RIFFLES | 166 | 0.568 | 0.967 | 4 |
| RUNS | 166 | 5.020 | 0.280 | 4 |
| RAPIDS | 166 | 2.356 | 0.671 | 4 |
| BEDROCK | 166 | 7.280 | 0.122 | 4 |
| BOULDER | 166 | 8.656 | 0.070 | 4 |
| COBBLE | 166 | 6.308 | 0.177 | 4 |
| RUBBLE | 166 | 4.430 | 0.351 | 4 |
| GRAVEL | 166 | 2.983 | 0.561 | 3 |
| SAND | 166 | 6.783 | 0.148 | 4 |
| SILT_CLA | 166 | 4.868 | 0.301 | 4 |
| HARD_PAN | 166 | 8.765 | 0.067 | 4 |
| DETRITUS | 166 | 1.506 | 0.826 | 4 |
| VEGETANA | 166 | 7.115 | 0.130 | 4 |
| ALGAEA | 166 | 7.688 | 0.104 | 4 |
| WOODA | 166 | 4.797 | 0.309 | 4 |
| SUBSTRTA | 166 | 8.454 | 0.076 | 4 |
| OVERHEDA | 166 | 3.646 | 0.456 | 4 |
| TURBIDYA | 166 | 6.025 | 0.197 | 1 |
| POOLA | 166 | 6.102 | 0.192 | 3 |
| RIFFLEA | 166 | 2.481 | 0.648 | 4 |
| RUNA | 166 | 3.750 | 0.441 | 4 |
| RAPIDA | 166 | 2.836 | 0.586 | 4 |
| MAXAGEL | 163 | 8.055 | 0.090 | 1.792 |
| MAXLENL | 165 | 9.006 | 0.061 | 5.187 |
| *REPLENL | 160 | 9.870 | 0.043 | 4.454 |
| *REPAGEL | 158 | 11.447 | 0.022 | 0.693 |

Appendix I. Results of the Kruskal-Wallis nonparametric ANOVA for significance between variables with STATUS4 (mode conservation ranking) as the grouping variable. Significant variables ($p \leq 0.05$) are marked with an asterisk (*).

| Variable | N | H | *p* | MEDIAN |
|---|---|---|---|---|
| LAKE | 166 | 4.376 | 0.358 | 1 |
| *STREAM | 166 | 30.956 | 0.000 | 1 |
| VALUE | 166 | 9.025 | 0.061 | 1 |
| *BALON_GUILD | 161 | 15.884 | 0.003 | 5 |
| BO | 166 | 0.796 | 0.939 | 1 |
| PE | 166 | 1.172 | 0.883 | 2 |
| SU | 166 | 2.930 | 0.570 | 4 |
| NO | 166 | 4.561 | 0.335 | 4 |
| FI | 166 | 5.501 | 0.240 | 4 |
| GR | 166 | 2.395 | 0.666 | 1 |
| SO | 166 | 5.088 | 0.278 | 4 |
| ST | 166 | 2.556 | 0.635 | 4 |
| PU | 166 | 1.749 | 0.782 | 3 |
| AM | 166 | 2.741 | 0.602 | 4 |
| PH | 166 | 5.043 | 0.283 | 4 |
| MA | 166 | 7.642 | 0.106 | 4 |
| CR | 166 | 2.140 | 0.710 | 1 |
| AN | 166 | 3.216 | 0.522 | 4 |
| MO | 166 | 0.894 | 0.925 | 4 |
| *IN | 166 | 10.868 | 0.028 | 1 |
| FI2 | 166 | 5.640 | 0.228 | 4 |
| *PA | 166 | 11.907 | 0.018 | 4 |
| OT | 166 | 0.700 | 0.951 | 4 |
| VEGETANS | 166 | 4.148 | 0.386 | 4 |
| ALGAES | 166 | 4.748 | 0.314 | 4 |
| WOODS | 166 | 5.544 | 0.236 | 4 |
| SUBSTRTS | 166 | 3.485 | 0.480 | 4 |
| OVERHEDS | 166 | 3.162 | 0.531 | 4 |
| DEPTH1 | 166 | 4.591 | 0.332 | 4 |
| DEPTH2 | 166 | 2.387 | 0.665 | 4 |
| DEPTH3 | 166 | 3.746 | 0.441 | 4 |
| DEPTH4 | 166 | 1.196 | 0.879 | 4 |
| *DEPTH5 | 166 | 11.561 | 0.021 | 4 |

| *Appx. I cont.* Variables | N | H | *p* | MEDIAN |
|---|---|---|---|---|
| POOLS | 166 | 5.260 | 0.262 | 3 |
| RIFFLES | 166 | 0.346 | 0.987 | 4 |
| *RUNS | 166 | 9.755 | 0.045 | 4 |
| RAPIDS | 166 | 3.603 | 0.462 | 4 |
| BEDROCK | 166 | 5.983 | 0.200 | 4 |
| BOULDER | 166 | 4.466 | 0.347 | 4 |
| COBBLE | 166 | 6.046 | 0.196 | 4 |
| RUBBLE | 166 | 3.811 | 0.432 | 4 |
| GRAVEL | 166 | 2.247 | 0.690 | 3 |
| SAND | 166 | 6.877 | 0.143 | 4 |
| SILT_CLA | 166 | 5.031 | 0.284 | 4 |
| HARD_PAN | 166 | 5.916 | 0.206 | 4 |
| DETRITUS | 166 | 1.151 | 0.886 | 4 |
| VEGETANA | 166 | 7.090 | 0.131 | 4 |
| ALGAEA | 166 | 4.546 | 0.337 | 4 |
| WOODA | 166 | 4.692 | 0.230 | 4 |
| SUBSTRTA | 166 | 2.646 | 0.619 | 4 |
| OVERHEDA | 166 | 4.040 | 0.401 | 4 |
| TURBIDYA | 166 | 6.432 | 0.169 | 1 |
| POOLA | 166 | 7.842 | 0.098 | 3 |
| RIFFLEA | 166 | 5.235 | 0.264 | 4 |
| RUNA | 166 | 5.231 | 0.265 | 4 |
| RAPIDA | 166 | 2.111 | 0.715 | 4 |
| MAXAGEL | 163 | 9.808 | 0.044 | 1.792 |
| MAXLENL | 165 | 12.061 | 0.017 | 5.187 |
| REPLENL | 160 | 10.059 | 0.040 | 4.454 |
| REPAGEL | 158 | 11.982 | 0.018 | 0.693 |

Appendix J. Probabilities of correct classification of Great Lakes fish species as at-risk or not at-risk by the linear logistic regression model at a decision level of 50%. Species incorrectly classified are marked with an asterisk (*).

| Species | Observed | Predicted | % Probability |
|---|---|---|---|
| *Ichthyomyzon castaneus* | 1 | 0.7443 | 74.4 |
| *Ichthyomyzon fossor* | 1 | 0.7484 | 74.8 |
| *Ichthyomyzon unicuspis* | 1 | 0.8785 | 87.9 |
| *Lampetra appendix* | 1 | 0.7275 | 72.8 |
| *Acipenser fulvescens* | 1 | 0.6925 | 69.2 |
| *Polyodon spathula* | 1 | 0.9611 | 96.1 |
| **Lepisosteus oculatus* | 1 | 0.2520 | 25.2 |
| *Lepisosteus osseus* | 0 | 0.4398 | 44.0 |
| *Lepisosteus platostomus* | 0 | 0.3097 | 31.0 |
| *Amia calva* | 0 | 0.3507 | 35.1 |
| **Hiodon tergisus* | 1 | 0.3762 | 37.6 |
| *Anguilla rostrata* | 1 | 0.5340 | 53.4 |
| **Alosa pseudoharengus* | 0 | 0.6608 | 66.1 |
| *Alosa sapidissima* | 1 | 0.7252 | 72.5 |
| *Dorosoma cepedianum* | 0 | 0.4694 | 46.9 |
| *Campostoma anomalum* | 1 | 0.5844 | 58.4 |
| **Campostoma oligolepis* | 0 | 0.5844 | 58.4 |
| *Clinostomus elongatus* | 1 | 0.5576 | 55.8 |
| **Couesius plumbeus* | 0 | 0.5107 | 51.1 |
| *Cyprinella analostana* | 0 | 0.1931 | 19.3 |
| *Cyprinella spiloptera* | 0 | 0.2986 | 29.9 |
| **Erimystax x-punctatus* | 1 | 0.4492 | 44.9 |
| *Exoglossum laurae* | 1 | 0.5602 | 56.0 |
| *Exoglossum maxilingua* | 1 | 0.5495 | 54.9 |
| *Hybognathus hankinsoni* | 0 | 0.4534 | 45.3 |
| *Hybognathus regius* | 1 | 0.5923 | 59.2 |
| **Luxilis chrysocephalus* | 1 | 0.3152 | 31.5 |
| *Luxilis cornutus* | 0 | 0.4381 | 43.8 |
| **Lythrurus umbratilis* | 1 | 0.2945 | 29.5 |
| *Macrhybopsis storeriana* | 1 | 0.5364 | 53.6 |
| *Margariscus margarita* | 0 | 0.4157 | 41.6 |
| *Nocomis biguttatus* | 0 | 0.5024 | 50.2 |
| *Nocomis micropogon* | 1 | 0.5056 | 50.6 |
| **Notemigonus crysoleucas* | 0 | 0.6297 | 63.0 |
| **Notropis amblops* | 1 | 0.3066 | 30.7 |
| **Notropis atherinoides* | 0 | 0.6799 | 68.0 |

| *Appx. J cont.* Species | Observed | Predicted | % Probability |
|---|---|---|---|
| **Notropis bifrenatus* | 1 | 0.4323 | 43.2 |
| **Notropis blennius* | 0 | 0.5576 | 55.8 |
| *Notropis buccatus* | 0 | 0.4136 | 41.4 |
| *Notropis buchanani* | 0 | 0.4277 | 42.8 |
| *Notropis chalybaeus* | 0 | 0.2929 | 29.3 |
| **Notropis dorsalis* | 1 | 0.4035 | 40.4 |
| **Notropis heterodon* | 1 | 0.4333 | 43.3 |
| **Notropis heterolepis* | 1 | 0.2888 | 28.9 |
| *Notropis hudsonius* | 0 | 0.2182 | 21.8 |
| **Notropis photogenis* | 1 | 0.4467 | 44.7 |
| *Notropis procne* | 0 | 0.4050 | 40.5 |
| *Notropis rubellus* | 0 | 0.3284 | 32.8 |
| *Notropis stramineus* | 0 | 0.2917 | 29.2 |
| **Notropis texanus* | 1 | 0.3434 | 34.3 |
| *Notropis volucellus* | 0 | 0.4443 | 44.4 |
| *Phoxinus eos* | 0 | 0.4480 | 44.8 |
| *Phoxinus erythrogaster* | 1 | 0.5870 | 58.7 |
| **Phoxinus neogaeus* | 0 | 0.5533 | 55.3 |
| *Pimephales notatus* | 0 | 0.4268 | 42.7 |
| *Pimephales promelas* | 0 | 0.4282 | 42.8 |
| *Pimephales vigilax* | 0 | 0.4002 | 40.0 |
| *Rhinichthys atratulus* | 0 | 0.4050 | 40.5 |
| **Rhinichthys cataractae* | 0 | 0.5589 | 55.9 |
| *Semotilus atromaculatus* | 0 | 0.4101 | 41.0 |
| *Semotilus corporalis* | 0 | 0.4393 | 43.9 |
| **Carpiodes cyprinus* | 0 | 0.6142 | 61.4 |
| *Catostomus catostomus* | 1 | 0.7142 | 71.4 |
| **Catostomus commersoni* | 0 | 0.6595 | 66.0 |
| *Erimyzon oblongus* | 1 | 0.5851 | 58.5 |
| *Erimyzon sucetta* | 1 | 0.6468 | 64.7 |
| **Hypentelium nigricans* | 0 | 0.6316 | 63.2 |
| *Ictiobus cyprinellus* | 1 | 0.6980 | 69.8 |
| *Ictiobus niger* | 1 | 0.8232 | 82.3 |
| *Lagochila lacera* | 1 | 0.6719 | 67.2 |
| *Minytrema melanops* | 1 | 0.6439 | 64.4 |
| **Moxostoma anisurum* | 0 | 0.7203 | 72.0 |
| *Moxostoma carinatum* | 1 | 0.7179 | 71.8 |
| *Moxostoma duquesnei* | 1 | 0.6411 | 64.1 |

| Appx. J cont. Species | Observed | Predicted | % Probability |
|---|---|---|---|
| *Moxostoma erythrurum* | 1 | 0.5443 | 54.4 |
| **Moxostoma hubbsi* | 0 | 0.7157 | 71.6 |
| **Moxostoma macrolepidotum* | 0 | 0.6383 | 63.8 |
| *Moxostoma valenciennesi* | 1 | 0.7313 | 73.1 |
| *Ameiurus catus* | 0 | 0.2169 | 21.7 |
| **Ameiurus melas* | 1 | 0.3426 | 34.3 |
| *Ameiurus natalis* | 0 | 0.4440 | 44.4 |
| *Ameiurus nebulosus* | 0 | 0.3585 | 35.8 |
| *Ictalurus punctatus* | 0 | 0.2578 | 25.8 |
| *Noturus flavus* | 0 | 0.3746 | 37.5 |
| *Noturus gyrinus* | 0 | 0.3679 | 36.8 |
| **Noturus insignis* | 1 | 0.4306 | 43.1 |
| *Noturus miurus* | 1 | 0.5130 | 51.3 |
| **Noturus stigmosus* | 1 | 0.4853 | 48.5 |
| *Pylodictis olivaris* | 0 | 0.3769 | 37.7 |
| **Esox americanus vermiculatus* | 1 | 0.2985 | 29.9 |
| **Esox lucius* | 0 | 0.5666 | 56.7 |
| **Esox masquinongy* | 1 | 0.3566 | 35.7 |
| **Esox niger* | 0 | 0.5811 | 58.1 |
| *Umbra limi* | 0 | 0.1641 | 16.4 |
| *Coregonus artedi* | 1 | 0.8774 | 87.7 |
| *Coregonus clupeaformis* | 1 | 0.5105 | 51.1 |
| *Coregonus hoyi* | 1 | 0.9687 | 96.9 |
| *Coregonus kiyi* | 1 | 0.9696 | 97.0 |
| *Coregonus nigripinnis* | 1 | 0.9737 | 97.4 |
| *Coregonus zenithicus* | 1 | 0.9605 | 96.1 |
| *Prosopium coulteri* | 1 | 0.8133 | 81.3 |
| *Prosopium cylindraceum* | 1 | 0.7368 | 73.7 |
| *Salmo salar* | 1 | 0.7618 | 76.2 |
| **Salvelinus fontinalis* | 1 | 0.2430 | 24.3 |
| *Salvelinus namaycush* | 1 | 0.8095 | 80.9 |
| **Thymallus arcticus* | 1 | 0.4904 | 49.0 |
| *Percopsis omiscomaycus* | 0 | 0.2800 | 28.0 |
| **Aphredoderus sayanus* | 1 | 0.3706 | 37.1 |
| *Lota lota* | 1 | 0.6089 | 60.9 |
| *Fundulus diaphanus* | 1 | 0.5499 | 55.0 |
| **Fundulus heteroclitus* | 0 | 0.2208 | 22.1 |
| **Fundulus notatus* | 1 | 0.4381 | 43.8 |

| Appx. J cont. Species | Observed | Predicted | % Probability |
|---|---|---|---|
| *Labidesthes sicculus* | 0 | 0.3088 | 30.9 |
| *Culaea inconstans* | 0 | 0.4295 | 42.9 |
| *Gasterosteus aculeatus* | 0 | 0.1344 | 13.4 |
| *Pungitius pungitius* | 0 | 0.4135 | 41.3 |
| *Cottus bairdi* | 0 | 0.1810 | 18.1 |
| *Cottus cognatus* | 0 | 0.4855 | 48.6 |
| *Myoxocephalus thompsoni* | 1 | 0.7020 | 70.2 |
| *Morone chrysops* | 0 | 0.3537 | 35.4 |
| *Ambloplites rupestris* | 0 | 0.1829 | 18.3 |
| *Enneacanthus gloriosus* | 0 | 0.3951 | 39.5 |
| *Lepomis cyanellus* | 0 | 0.1244 | 12.4 |
| *Lepomis gibbosus* | 0 | 0.2682 | 26.8 |
| **Lepomis gulosus* | 1 | 0.1422 | 14.2 |
| **Lepomis humilis* | 1 | 0.2880 | 28.8 |
| *Lepomis macrochirus* | 0 | 0.3281 | 32.8 |
| **Lepomis megalotis* | 1 | 0.2320 | 23.2 |
| **Lepomis microlophus* | 0 | 0.6515 | 65.1 |
| *Micropterus dolomieu* | 0 | 0.3951 | 39.5 |
| *Micropterus salmoides* | 0 | 0.1669 | 16.7 |
| **Pomoxis annularis* | 1 | 0.1508 | 15.1 |
| *Pomoxis nigromaculatus* | 0 | 0.2604 | 26.0 |
| *Ammocrypta clara* | 0 | 0.2947 | 29.5 |
| **Ammocrypta pellucida* | 1 | 0.2951 | 29.5 |
| **Etheostoma blennioides* | 1 | 0.4410 | 44.1 |
| *Etheostoma caeruleum* | 0 | 0.2968 | 29.7 |
| **Etheostoma chlorosomum* | 1 | 0.4331 | 43.3 |
| **Etheostoma exile* | 1 | 0.3002 | 30.0 |
| **Etheostoma flabellare* | 0 | 0.5384 | 53.8 |
| **Etheostoma microperca* | 1 | 0.4306 | 43.1 |
| *Etheostoma nigrum* | 0 | 0.2865 | 28.7 |
| *Etheostoma olmstedi* | 0 | 0.2877 | 28.8 |
| *Etheostoma spectabile* | 0 | 0.2935 | 29.4 |
| *Etheostoma zonale* | 0 | 0.4323 | 43.2 |
| *Perca flavescens* | 0 | 0.3609 | 36.1 |
| *Percina caprodes* | 0 | 0.3876 | 38.8 |
| **Percina copelandi* | 1 | 0.4296 | 43.0 |
| *Percina evides* | 0 | 0.3066 | 30.7 |
| *Percina maculata* | 0 | 0.2740 | 27.4 |

| *Appx. J cont.* Species | Observed | Predicted | % Probability |
|---|---|---|---|
| *Percina phoxocephala* | 0 | 0.2975 | 29.7 |
| **Percina shumardi* | 1 | 0.4362 | 43.6 |
| **Stizostedion canadense* | 1 | 0.4336 | 43.4 |
| *Stizostedion vitreum* | 0 | 0.3291 | 32.9 |
| *Aplodinotus grunniens* | 0 | 0.4934 | 49.3 |

Appendix K. Summary of stepwise multiple regression model.

| Variables | Step +in/-out | Multiple R | Multiple R-square | R-square change | F - to entr/rem | *p*-level | Variables included |
|---|---|---|---|---|---|---|---|
| DEPTH5 | 1 | 0.2280 | 0.052 | 0.052 | 8.392 | 0.004 | 1 |
| FI2 | 2 | 0.2821 | 0.080 | 0.028 | 4.555 | 0.034 | 2 |
| REPAGEL | 3 | 0.3695 | 0.136 | 0.057 | 9.954 | 0.002 | 3 |
| SAND | 4 | 0.3832 | 0.147 | 0.010 | 1.822 | 0.179 | 4 |
| STREAM | 5 | 0.3943 | 0.155 | 0.009 | 1.520 | 0.220 | 5 |

Appendix L. Predicted and observed values by the stepwise multiple regression for the number of jurisdictions in the Great Lakes basin within which a species is listed as at-risk. Correctly predicted numbers are marked with an asterisk (*).

| Species | Observed | Predicted |
|---|---|---|
| *Ichthyomyzon castaneus* | 1 | 2 |
| *Ichthyomyzon fossor* | 5 | 2 |
| *Ichthyomyzon unicuspis* | 1 | 2 |
| *Lampetra appendix* | 1 | 2 |
| *Acipenser fulvescens* | 9 | 2 |
| *Polyodon spathula* | 5 | 3 |
| *Lepisosteus oculatus* | 3 | 0 |
| *Lepisosteus osseus* | 0 | 1 |
| *Lepisosteus platostomus* | 0 | 1 |
| *Amia calva* | 0 | 1 |
| *Hiodon tergisus* | 2 | 1 |
| *Anguilla rostrata* | 2 | 1 |
| *Alosa pseudoharengus* | 0 | 1 |
| *Alosa sapidissima* | 1 | 2 |
| *Dorosoma cepedianum* | 0 | 1 |
| **Campostoma anomalum* | 1 | 1 |
| *Campostoma oligolepis* | 0 | 1 |
| *Clinostomus elongatus* | 4 | 1 |
| *Couesius plumbeus* | 0 | 1 |
| **Cyprinella analostana* | 0 | 0 |
| *Cyprinella spiloptera* | 0 | 1 |
| *Erimystax x-punctatus* | 5 | 1 |
| **Exoglossum laurae* | 1 | 1 |
| **Exoglossum maxilingua* | 1 | 1 |
| *Hybognathus hankinsoni* | 0 | 1 |
| **Hybognathus regius* | 1 | 1 |
| *Luxilis chrysocephalus* | 2 | 1 |
| *Luxilis cornutus* | 0 | 1 |
| *Lythrurus umbratilis* | 2 | 1 |
| *Macrhybopsis storeriana* | 4 | 1 |
| *Margariscus margarita* | 0 | 1 |
| *Nocomis biguttatus* | 0 | 1 |
| **Nocomis micropogon* | 1 | 1 |
| *Notemigonus crysoleucas* | 0 | 1 |

| Appx. L cont. Species | Observed | Predicted |
| --- | --- | --- |
| *Notropis amblops | 1 | 1 |
| Notropis atherinoides | 0 | 2 |
| *Notropis bifrenatus | 1 | 1 |
| Notropis blennius | 0 | 1 |
| Notropis boops | 0 | 1 |
| Notropis buccatus | 0 | 1 |
| Notropis buchanani | 0 | 1 |
| Notropis chalybaeus | 0 | 1 |
| *Notropis dorsalis | 1 | 1 |
| Notropis heterodon | 2 | 1 |
| Notropis heterolepis | 2 | 1 |
| *Notropis hudsonius | 0 | 0 |
| Notropis photogenis | 2 | 1 |
| Notropis procne | 0 | 1 |
| *Notropis rubellus | 0 | 0 |
| Notropis stramineus | 0 | 1 |
| Notropis texanus | 3 | 1 |
| Notropis volucellus | 0 | 1 |
| Phenacobius mirabilis | 0 | 1 |
| Phoxinus eos | 0 | 1 |
| *Phoxinus erythrogaster | 1 | 1 |
| Phoxinus neogaeus | 0 | 1 |
| Pimephales notatus | 0 | 1 |
| Pimephales promelas | 0 | 1 |
| Pimephales vigilax | 0 | 1 |
| Rhinichthys atratulus | 0 | 1 |
| Rhinichthys cataractae | 0 | 1 |
| Semotilus atromaculatus | 0 | 1 |
| Semotilus corporalis | 0 | 1 |
| Carpiodes cyprinus | 0 | 2 |
| Catostomus catostomus | 3 | 2 |
| Catostomus commersoni | 0 | 2 |
| *Erimyzon oblongus | 1 | 1 |
| Erimyzon sucetta | 4 | 1 |
| Hypentelium nigricans | 0 | 1 |
| Ictiobus cyprinellus | 1 | 2 |

| *Appx. L cont.* Species | Observed | Predicted |
|---|---|---|
| *Ictiobus niger* | 4 | 2 |
| *Lagochila lacera* | 2 | 1 |
| **Minytrema melanops* | 1 | 1 |
| *Moxostoma anisurum* | 0 | 2 |
| *Moxostoma carinatum* | 6 | 2 |
| *Moxostoma duquesnei* | 3 | 1 |
| **Moxostoma erythrurum* | 1 | 1 |
| *Moxostoma hubbsi* | 0 | 2 |
| *Moxostoma macrolepidotum* | 0 | 1 |
| *Moxostoma valenciennesi* | 4 | 2 |
| **Ameiurus catus* | 0 | 0 |
| **Ameiurus melas* | 1 | 1 |
| *Ameiurus natalis* | 0 | 1 |
| *Ameiurus nebulosus* | 0 | 1 |
| *Ictalurus punctatus* | 0 | 1 |
| *Noturus flavus* | 0 | 1 |
| *Noturus gyrinus* | 0 | 1 |
| **Noturus insignis* | 1 | 1 |
| *Noturus miurus* | 2 | 1 |
| *Noturus stigmosus* | 5 | 1 |
| *Pylodictis olivaris* | 0 | 1 |
| **Esox americanus vermiculatus* | 1 | 1 |
| *Esox lucius* | 0 | 1 |
| *Esox masquinongy* | 2 | 1 |
| *Esox niger* | 0 | 2 |
| **Umbra limi* | 0 | 0 |
| *Coregonus artedi* | 5 | 2 |
| *Coregonus clupeaformis* | 1 | 2 |
| *Coregonus hoyi* | 1 | 3 |
| *Coregonus kiyi* | 4 | 3 |
| **Coregonus nigripinnis* | 3 | 3 |
| *Coregonus zenithicus* | 4 | 3 |
| *Prosopium coulteri* | 1 | 2 |
| *Prosopium cylindraceum* | 1 | 2 |
| **Salmo salar* | 1 | 1 |
| *Salvelinus fontinalis* | 2 | 1 |
| *Salvelinus namaycush* | 1 | 2 |
| **Thymallus arcticus* | 1 | 1 |

| *Appx. L cont.* Species | Observed | Predicted |
|---|---|---|
| *Percopsis omiscomaycus* | 0 | 1 |
| *Aphredoderus sayanus* | 3 | 1 |
| *Lota lota* | 2 | 1 |
| *Fundulus diaphanus* | 3 | 1 |
| **Fundulus heteroclitus* | 0 | 0 |
| **Fundulus notatus* | 1 | 1 |
| **Gambusia affinis* | 0 | 0 |
| *Labidesthes sicculus* | 0 | 1 |
| *Culaea inconstans* | 0 | 1 |
| **Gasterosteus aculeatus* | 0 | 0 |
| *Pungitius pungitius* | 0 | 1 |
| **Cottus bairdi* | 0 | 0 |
| *Cottus cognatus* | 0 | 1 |
| *Myoxocephalus thompsoni* | 1 | 2 |
| *Morone chrysops* | 0 | 1 |
| **Ambloplites rupestris* | 0 | 0 |
| *Enneacanthus gloriosus* | 0 | 1 |
| **Lepomis cyanellus* | 0 | 0 |
| *Lepomis gibbosus* | 0 | 1 |
| *Lepomis gulosus* | 1 | 0 |
| *Lepomis humilis* | 1 | 1 |
| *Lepomis macrochirus* | 0 | 1 |
| *Lepomis megalotis* | 3 | 1 |
| *Lepomis microlophus* | 0 | 1 |
| *Micropterus dolomieu* | 0 | 1 |
| **Micropterus salmoides* | 0 | 0 |
| *Pomoxis annularis* | 1 | 0 |
| *Pomoxis nigromaculatus* | 0 | 1 |
| *Ammocrypta clara* | 0 | 1 |
| *Ammocrypta pellucida* | 6 | 1 |
| **Etheostoma blennioides* | 1 | 1 |
| *Etheostoma caeruleum* | 0 | 1 |
| **Etheostoma chlorosomum* | 1 | 1 |
| *Etheostoma exile* | 2 | 1 |
| *Etheostoma flabellare* | 0 | 1 |
| *Etheostoma microperca* | 3 | 1 |

| *Appx. L cont.* Species | Observed | Predicted |
|---|---|---|
| *Etheostoma nigrum* | 0 | 1 |
| *Etheostoma olmstedi* | 0 | 1 |
| *Etheostoma spectabile* | 0 | 1 |
| *Etheostoma zonale* | 0 | 1 |
| *Perca flavescens* | 0 | 1 |
| *Percina caprodes* | 0 | 1 |
| *Percina copelandi* | 5 | 1 |
| *Percina evides* | 0 | 1 |
| *Percina maculata* | 0 | 1 |
| *Percina phoxocephala* | 0 | 1 |
| *Percina shumardi* | 3 | 1 |
| **Stizostedion canadense* | 1 | 1 |
| *Stizostedion vitreum* | 0 | 1 |
| *Aplodinotus grunniens* | 0 | 1 |

Appendix M. Conservation ranks for Great Lakes fishes determined from the discriminant function analysis of STATUS3. Species were re-classified to the rank with the largest predicted value to one of five possible ranks (0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated). Incorrectly ranked species are marked with an asterisk (*).

| Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Ichthyomyzon castaneus* | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| *Ichthyomyzon fossor* | 3 | 0.007 | 0.454 | 0.002 | 0.537 | 0.000 |
| *Ichthyomyzon unicuspis* | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| *Lampetra appendix* | 1 | 0.020 | 0.924 | 0.000 | 0.056 | 0.000 |
| **Acipenser fulvescens* | 3 | 0.555 | 0.038 | 0.014 | 0.393 | 0.000 |
| *Polyodon spathula* | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| *Lepisosteus oculatus* | 3 | 0.217 | 0.004 | 0.093 | 0.685 | 0.000 |
| *Lepisosteus osseus* | 0 | 0.875 | 0.014 | 0.047 | 0.064 | 0.000 |
| **Amia calva* | 0 | 0.029 | 0.003 | 0.964 | 0.004 | 0.000 |
| *Hiodon tergisus* | 3 | 0.081 | 0.000 | 0.034 | 0.885 | 0.000 |
| **Anguilla rostrata* | 2 | 0.323 | 0.001 | 0.197 | 0.479 | 0.000 |
| *Alosa pseudoharengus* | 0 | 0.876 | 0.000 | 0.027 | 0.013 | 0.084 |
| *Alosa sapidissima* | 4 | 0.037 | 0.000 | 0.007 | 0.000 | 0.956 |
| *Dorosoma cepedianum* | 0 | 0.926 | 0.000 | 0.064 | 0.010 | 0.000 |
| **Campostoma anomalum* | 1 | 0.632 | 0.321 | 0.012 | 0.035 | 0.000 |
| *Campostoma oligolepis* | 0 | 0.995 | 0.001 | 0.000 | 0.004 | 0.000 |
| *Clinostomus elongatus* | 3 | 0.197 | 0.000 | 0.119 | 0.684 | 0.000 |
| *Couesius plumbeus* | 0 | 0.934 | 0.000 | 0.001 | 0.065 | 0.000 |
| *Cyprinella analostana* | 0 | 0.988 | 0.000 | 0.011 | 0.001 | 0.000 |
| *Cyprinella spiloptera* | 0 | 0.965 | 0.000 | 0.024 | 0.011 | 0.000 |
| *Erimystax x-punctatus* | 3 | 0.075 | 0.000 | 0.001 | 0.923 | 0.000 |
| **Exoglossum laurae* | 2 | 0.095 | 0.001 | 0.062 | 0.842 | 0.000 |
| *Exoglossum maxilingua* | 3 | 0.082 | 0.000 | 0.084 | 0.834 | 0.000 |
| *Hybognathus hankinsoni* | 0 | 0.988 | 0.000 | 0.004 | 0.007 | 0.000 |
| *Hybognathus regius* | 2 | 0.057 | 0.001 | 0.692 | 0.250 | 0.000 |
| *Luxilis chrysocephalus* | 3 | 0.043 | 0.000 | 0.007 | 0.950 | 0.000 |
| **Luxilis cornutus* | 0 | 0.296 | 0.001 | 0.641 | 0.061 | 0.001 |
| **Lythrurus umbratilis* | 2 | 0.800 | 0.000 | 0.171 | 0.029 | 0.000 |

| Appx. M cont. Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Macrhybopsis storeriana* | 3 | 0.234 | 0.001 | 0.012 | 0.753 | 0.000 |
| *Margariscus margarita* | 0 | 0.512 | 0.001 | 0.023 | 0.464 | 0.000 |
| *Nocomis biguttatus* | 0 | 0.882 | 0.001 | 0.062 | 0.056 | 0.000 |
| *Nocomis micropogon* | 3 | 0.129 | 0.002 | 0.084 | 0.785 | 0.000 |
| *Notemigonus crysoleucas* | 0 | 0.825 | 0.079 | 0.007 | 0.088 | 0.001 |
| *Notropis amblops* | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| *Notropis atherinoides* | 0 | 0.621 | 0.014 | 0.002 | 0.362 | 0.000 |
| *Notropis bifrenatus* | 2 | 0.015 | 0.000 | 0.984 | 0.001 | 0.000 |
| **Notropis blennius* | 0 | 0.440 | 0.012 | 0.013 | 0.535 | 0.000 |
| *Notropis buccatus* | 0 | 0.814 | 0.001 | 0.020 | 0.165 | 0.000 |
| **Notropis buchanani* | 0 | 0.065 | 0.000 | 0.000 | 0.000 | 0.934 |
| *Notropis chalybaeus* | 0 | 0.890 | 0.005 | 0.065 | 0.040 | 0.000 |
| *Notropis dorsalis* | 2 | 0.331 | 0.000 | 0.370 | 0.299 | 0.000 |
| *Notropis heterodon* | 3 | 0.341 | 0.000 | 0.005 | 0.654 | 0.000 |
| **Notropis heterolepis* | 3 | 0.773 | 0.016 | 0.011 | 0.200 | 0.000 |
| *Notropis hudsonius* | 0 | 0.952 | 0.000 | 0.035 | 0.013 | 0.000 |
| *Notropis photogenis* | 3 | 0.084 | 0.001 | 0.009 | 0.905 | 0.001 |
| *Notropis procne* | 0 | 0.630 | 0.000 | 0.334 | 0.036 | 0.000 |
| *Notropis rubellus* | 0 | 0.984 | 0.000 | 0.001 | 0.015 | 0.000 |
| *Notropis stramineus* | 0 | 0.967 | 0.000 | 0.014 | 0.019 | 0.000 |
| *Notropis texanus* | 4 | 0.002 | 0.000 | 0.000 | 0.000 | 0.998 |
| **Notropis volucellus* | 0 | 0.446 | 0.006 | 0.495 | 0.054 | 0.000 |
| *Phoxinus eos* | 0 | 0.992 | 0.000 | 0.000 | 0.008 | 0.000 |
| **Phoxinus erythrogaster* | 3 | 0.558 | 0.001 | 0.002 | 0.438 | 0.000 |
| **Phoxinus neogaeus* | 0 | 0.252 | 0.000 | 0.008 | 0.740 | 0.000 |
| *Pimephales notatus* | 0 | 0.573 | 0.001 | 0.002 | 0.424 | 0.000 |
| *Pimephales promelas* | 0 | 0.788 | 0.000 | 0.017 | 0.195 | 0.000 |
| *Pimephales vigilax* | 0 | 0.985 | 0.002 | 0.004 | 0.009 | 0.000 |
| *Rhinichthys atratulus* | 0 | 0.982 | 0.000 | 0.002 | 0.016 | 0.000 |
| *Rhinichthys cataractae* | 0 | 0.987 | 0.000 | 0.005 | 0.008 | 0.000 |
| *Semotilus atromaculatus* | 0 | 0.690 | 0.000 | 0.011 | 0.299 | 0.000 |
| *Semotilus corporalis* | 0 | 0.771 | 0.000 | 0.030 | 0.198 | 0.000 |
| **Carpiodes cyprinus* | 0 | 0.412 | 0.000 | 0.548 | 0.040 | 0.000 |
| **Catostomus catostomus* | 3 | 0.984 | 0.000 | 0.001 | 0.014 | 0.000 |

Appx. M cont.

| Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Catostomus commersoni* | 0 | 0.976 | 0.000 | 0.000 | 0.019 | 0.004 |
| *Erimyzon oblongus* | 3 | 0.169 | 0.005 | 0.007 | 0.819 | 0.000 |
| *Erimyzon sucetta* | 2 | 0.075 | 0.000 | 0.879 | 0.046 | 0.000 |
| *Hypentelium nigricans* | 0 | 0.628 | 0.009 | 0.099 | 0.264 | 0.000 |
| *Ictiobus cyprinellus* | 1 | 0.013 | 0.973 | 0.013 | 0.001 | 0.000 |
| *Ictiobus niger* | 2 | 0.020 | 0.002 | 0.875 | 0.103 | 0.000 |
| *Lagochila lacera* | 4 | 0.225 | 0.000 | 0.004 | 0.019 | 0.752 |
| *Minytrema melanops* | 2 | 0.105 | 0.001 | 0.860 | 0.033 | 0.000 |
| *Moxostoma anisurum* | 0 | 0.822 | 0.006 | 0.129 | 0.042 | 0.000 |
| *Moxostoma carinatum* | 3 | 0.244 | 0.000 | 0.007 | 0.749 | 0.000 |
| *Moxostoma duquesnei* | 2 | 0.133 | 0.001 | 0.760 | 0.105 | 0.000 |
| *Moxostoma erythrurum* | 1 | 0.040 | 0.899 | 0.005 | 0.056 | 0.000 |
| **Moxostoma hubbsi* | 0 | 0.106 | 0.239 | 0.555 | 0.100 | 0.000 |
| *Moxostoma macrolepidotum* | 0 | 0.997 | 0.000 | 0.001 | 0.002 | 0.000 |
| *Moxostoma valenciennesi* | 3 | 0.238 | 0.060 | 0.030 | 0.559 | 0.113 |
| *Ameiurus catus* | 0 | 0.999 | 0.000 | 0.001 | 0.001 | 0.000 |
| **Ameiurus melas* | 1 | 0.746 | 0.007 | 0.171 | 0.077 | 0.000 |
| *Ameiurus natalis* | 0 | 0.954 | 0.006 | 0.001 | 0.027 | 0.012 |
| *Ameiurus nebulosus* | 0 | 0.719 | 0.000 | 0.279 | 0.002 | 0.000 |
| *Ictalurus punctatus* | 0 | 0.987 | 0.000 | 0.001 | 0.011 | 0.000 |
| *Noturus flavus* | 0 | 0.511 | 0.000 | 0.030 | 0.460 | 0.000 |
| *Noturus gyrinus* | 0 | 0.929 | 0.000 | 0.055 | 0.016 | 0.000 |
| *Noturus insignis* | 3 | 0.033 | 0.004 | 0.106 | 0.858 | 0.000 |
| *Noturus miurus* | 2 | 0.003 | 0.000 | 0.996 | 0.001 | 0.000 |
| **Pylodictis olivaris* | 0 | 0.376 | 0.094 | 0.035 | 0.495 | 0.000 |
| **Esox americanus vermiculatus* | 1 | 0.931 | 0.001 | 0.010 | 0.058 | 0.000 |
| *Esox lucius* | 0 | 0.762 | 0.011 | 0.007 | 0.220 | 0.000 |
| **Esox masquinongy* | 2 | 0.797 | 0.006 | 0.194 | 0.004 | 0.000 |
| *Esox niger* | 0 | 0.948 | 0.006 | 0.001 | 0.044 | 0.000 |
| *Umbra limi* | 0 | 0.738 | 0.001 | 0.008 | 0.253 | 0.000 |
| **Coregonus artedi* | 3 | 0.439 | 0.194 | 0.155 | 0.210 | 0.000 |
| *Coregonus clupeaformis* | 1 | 0.002 | 0.997 | 0.000 | 0.001 | 0.000 |
| *Coregonus hoyi* | 1 | 0.005 | 0.911 | 0.018 | 0.007 | 0.060 |
| *Coregonus kiyi* | 1 | 0.007 | 0.873 | 0.021 | 0.007 | 0.091 |

| Appx. M cont. Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Coregonus nigripinnis | 4 | 0.006 | 0.896 | 0.051 | 0.009 | 0.037 |
| *Coregonus zenithicus | 2 | 0.060 | 0.089 | 0.244 | 0.007 | 0.600 |
| *Prosopium coulteri | 1 | 0.058 | 0.328 | 0.078 | 0.535 | 0.000 |
| Prosopium cylindraceum | 3 | 0.077 | 0.003 | 0.022 | 0.899 | 0.000 |
| Salmo salar | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| *Salvelinus fontinalis | 2 | 0.577 | 0.000 | 0.418 | 0.004 | 0.001 |
| Salvelinus namaycush | 1 | 0.017 | 0.943 | 0.002 | 0.038 | 0.000 |
| Thymallus arcticus | 4 | 0.133 | 0.000 | 0.003 | 0.033 | 0.830 |
| Percopsis omiscomaycus | 0 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Aphredoderus sayanus | 3 | 0.162 | 0.000 | 0.019 | 0.819 | 0.000 |
| *Lota lota | 2 | 0.863 | 0.000 | 0.104 | 0.032 | 0.000 |
| Fundulus diaphanus | 3 | 0.068 | 0.001 | 0.039 | 0.893 | 0.000 |
| Fundulus heteroclitus | 0 | 0.944 | 0.000 | 0.020 | 0.036 | 0.000 |
| Fundulus notatus | 2 | 0.138 | 0.000 | 0.819 | 0.043 | 0.000 |
| Labidesthes sicculus | 0 | 0.923 | 0.000 | 0.065 | 0.012 | 0.000 |
| Culaea inconstans | 0 | 0.580 | 0.000 | 0.004 | 0.416 | 0.000 |
| Gasterosteus aculeatus | 0 | 0.567 | 0.431 | 0.000 | 0.002 | 0.000 |
| Pungitius pungitius | 0 | 0.849 | 0.117 | 0.002 | 0.032 | 0.000 |
| Cottus bairdi | 0 | 0.990 | 0.000 | 0.001 | 0.009 | 0.000 |
| Cottus cognatus | 0 | 0.914 | 0.001 | 0.001 | 0.084 | 0.000 |
| Myoxocephalus thompsoni | 3 | 0.418 | 0.009 | 0.151 | 0.423 | 0.000 |
| Morone chrysops | 0 | 0.983 | 0.000 | 0.001 | 0.016 | 0.000 |
| Ambloplites rupestris | 0 | 0.979 | 0.000 | 0.013 | 0.008 | 0.000 |
| Enneacanthus gloriosus | 0 | 0.966 | 0.000 | 0.027 | 0.007 | 0.000 |
| Lepomis cyanellus | 0 | 0.971 | 0.002 | 0.018 | 0.009 | 0.000 |
| Lepomis gibbosus | 0 | 0.907 | 0.083 | 0.002 | 0.007 | 0.000 |
| *Lepomis gulosus | 3 | 0.775 | 0.000 | 0.211 | 0.013 | 0.000 |
| *Lepomis humilis | 1 | 0.918 | 0.068 | 0.003 | 0.011 | 0.000 |
| Lepomis macrochirus | 0 | 0.791 | 0.000 | 0.020 | 0.189 | 0.000 |
| *Lepomis megalotis | 2 | 0.327 | 0.004 | 0.187 | 0.482 | 0.000 |
| Lepomis microlophus | 0 | 0.503 | 0.000 | 0.020 | 0.004 | 0.472 |
| Micropterus dolomieu | 0 | 0.877 | 0.000 | 0.044 | 0.078 | 0.000 |
| Micropterus salmoides | 0 | 0.951 | 0.000 | 0.002 | 0.047 | 0.000 |
| Pomoxis annularis | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| Pomoxis nigromaculatus | 0 | 0.915 | 0.000 | 0.005 | 0.078 | 0.001 |
| Ammocrypta clara | 0 | 0.846 | 0.009 | 0.105 | 0.041 | 0.000 |

*Appx. M cont.*

| Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Ammocrypta pellucida* | 3 | 0.411 | 0.001 | 0.006 | 0.582 | 0.000 |
| *Etheostoma blennioides* | 1 | 0.000 | 0.996 | 0.000 | 0.004 | 0.000 |
| *Etheostoma caeruleum* | 0 | 0.716 | 0.000 | 0.021 | 0.263 | 0.000 |
| *Etheostoma chlorosomum* | 3 | 0.043 | 0.000 | 0.030 | 0.927 | 0.000 |
| **Etheostoma exile* | 3 | 0.079 | 0.816 | 0.000 | 0.104 | 0.000 |
| *Etheostoma flabellare* | 0 | 0.761 | 0.062 | 0.001 | 0.175 | 0.000 |
| *Etheostoma microperca* | 1 | 0.006 | 0.988 | 0.000 | 0.005 | 0.000 |
| *Etheostoma nigrum* | 0 | 0.972 | 0.000 | 0.004 | 0.024 | 0.000 |
| *Etheostoma olmstedi* | 0 | 0.923 | 0.000 | 0.037 | 0.040 | 0.000 |
| *Etheostoma spectabile* | 0 | 0.537 | 0.002 | 0.012 | 0.449 | 0.000 |
| *Etheostoma zonale* | 0 | 0.937 | 0.002 | 0.053 | 0.008 | 0.000 |
| *Perca flavescens* | 0 | 0.616 | 0.002 | 0.198 | 0.184 | 0.000 |
| *Percina caprodes* | 0 | 0.770 | 0.000 | 0.032 | 0.197 | 0.000 |
| *Percina copelandi* | 3 | 0.235 | 0.000 | 0.003 | 0.761 | 0.000 |
| **Percina evides* | 0 | 0.358 | 0.001 | 0.009 | 0.631 | 0.000 |
| *Percina maculata* | 0 | 0.957 | 0.001 | 0.024 | 0.018 | 0.000 |
| *Percina phoxocephala* | 0 | 0.986 | 0.000 | 0.002 | 0.012 | 0.000 |
| **Percina shumardi* | 3 | 0.538 | 0.007 | 0.029 | 0.426 | 0.000 |
| *Stizostedion canadense* | 0 | 0.871 | 0.000 | 0.004 | 0.124 | 0.001 |
| **Stizostedion vitreum* | 0 | 0.438 | 0.000 | 0.013 | 0.032 | 0.517 |
| *Aplodinotus grunniens* | 0 | 0.531 | 0.000 | 0.006 | 0.463 | 0.000 |

Appendix N. Conservation ranks for Great Lakes fishes determined by the stepwise discriminant function analysis of STATUS3. Species were re-classified to the rank with the largest predicted value to one of five possible ranks (0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated). Incorrectly ranked species are marked with an asterisk (*).

| Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Ichthyomyzon castaneus* | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| **Ichthyomyzon fossor* | 3 | 0.025 | 0.599 | 0.005 | 0.371 | 0.000 |
| *Ichthyomyzon unicuspis* | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| *Lampetra appendix* | 1 | 0.020 | 0.875 | 0.004 | 0.101 | 0.000 |
| **Acipenser fulvescens* | 3 | 0.750 | 0.078 | 0.027 | 0.144 | 0.001 |
| *Polyodon spathula* | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| **Lepisosteus oculatus* | 3 | 0.314 | 0.014 | 0.438 | 0.234 | 0.000 |
| *Lepisosteus osseus* | 0 | 0.815 | 0.013 | 0.119 | 0.053 | 0.000 |
| **Amia calva* | 0 | 0.313 | 0.030 | 0.532 | 0.124 | 0.000 |
| *Hiodon tergisus* | 3 | 0.193 | 0.000 | 0.072 | 0.735 | 0.000 |
| **Anguilla rostrata* | 2 | 0.528 | 0.002 | 0.088 | 0.382 | 0.000 |
| *Alosa pseudoharengus* | 0 | 0.683 | 0.006 | 0.063 | 0.236 | 0.012 |
| *Alosa sapidissima* | 4 | 0.190 | 0.010 | 0.247 | 0.026 | 0.527 |
| *Dorosoma cepedianum* | 0 | 0.929 | 0.003 | 0.013 | 0.054 | 0.000 |
| **Campostoma anomalum* | 1 | 0.677 | 0.235 | 0.043 | 0.043 | 0.001 |
| *Campostoma oligolepis* | 0 | 0.938 | 0.022 | 0.016 | 0.024 | 0.000 |
| **Clinostomus elongatus* | 3 | 0.386 | 0.000 | 0.385 | 0.227 | 0.002 |
| *Couesius plumbeus* | 0 | 0.902 | 0.000 | 0.021 | 0.077 | 0.000 |
| *Cyprinella analostana* | 0 | 0.796 | 0.005 | 0.123 | 0.076 | 0.000 |
| *Cyprinella spiloptera* | 0 | 0.685 | 0.005 | 0.178 | 0.131 | 0.000 |
| *Erimystax x-punctatus* | 3 | 0.369 | 0.000 | 0.041 | 0.590 | 0.000 |
| **Exoglossum laurae* | 2 | 0.193 | 0.001 | 0.198 | 0.608 | 0.000 |
| *Exoglossum maxilingua* | 3 | 0.228 | 0.000 | 0.037 | 0.735 | 0.000 |
| *Hybognathus hankinsoni* | 0 | 0.944 | 0.000 | 0.008 | 0.047 | 0.000 |
| **Hybognathus regius* | 2 | 0.444 | 0.005 | 0.338 | 0.214 | 0.000 |
| **Luxilis chrysocephalus* | 3 | 0.627 | 0.001 | 0.022 | 0.350 | 0.000 |
| *Luxilis cornutus* | 0 | 0.704 | 0.003 | 0.203 | 0.079 | 0.010 |
| **Lythrurus umbratilis* | 2 | 0.867 | 0.001 | 0.064 | 0.068 | 0.000 |
| **Macrhybopsis storeriana* | 3 | 0.470 | 0.001 | 0.293 | 0.236 | 0.000 |
| *Margariscus margarita* | 0 | 0.556 | 0.003 | 0.080 | 0.360 | 0.001 |
| *Nocomis biguttatus* | 0 | 0.825 | 0.010 | 0.044 | 0.121 | 0.000 |
| **Nocomis micropogon* | 3 | 0.408 | 0.017 | 0.267 | 0.307 | 0.001 |
| *Notemigonus crysoleucas* | 0 | 0.551 | 0.088 | 0.317 | 0.037 | 0.007 |

| Appx. N cont. Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Notropis amblops* | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| *Notropis ariommus* | 0 | 0.787 | 0.001 | 0.090 | 0.122 | 0.000 |
| **Notropis atherinoides* | 0 | 0.369 | 0.020 | 0.015 | 0.596 | 0.000 |
| **Notropis bifrenatus* | 2 | 0.666 | 0.002 | 0.298 | 0.034 | 0.000 |
| *Notropis blennius* | 0 | 0.667 | 0.001 | 0.029 | 0.303 | 0.000 |
| **Notropis buccatus* | 0 | 0.307 | 0.004 | 0.189 | 0.500 | 0.000 |
| **Notropis buchanani* | 0 | 0.003 | 0.000 | 0.000 | 0.000 | 0.997 |
| *Notropis chalybaeus* | 0 | 0.638 | 0.001 | 0.105 | 0.257 | 0.000 |
| **Notropis dorsalis* | 2 | 0.499 | 0.001 | 0.058 | 0.442 | 0.000 |
| **Notropis heterodon* | 3 | 0.680 | 0.000 | 0.012 | 0.307 | 0.000 |
| **Notropis heterolepis* | 3 | 0.799 | 0.005 | 0.010 | 0.187 | 0.000 |
| *Notropis hudsonius* | 0 | 0.919 | 0.001 | 0.008 | 0.072 | 0.000 |
| *Notropis photogenis* | 3 | 0.187 | 0.000 | 0.094 | 0.719 | 0.000 |
| *Notropis procne* | 0 | 0.919 | 0.000 | 0.061 | 0.020 | 0.000 |
| *Notropis rubellus* | 0 | 0.973 | 0.000 | 0.009 | 0.018 | 0.000 |
| *Notropis stramineus* | 0 | 0.956 | 0.000 | 0.038 | 0.006 | 0.000 |
| *Notropis texanus* | 4 | 0.080 | 0.000 | 0.001 | 0.001 | 0.919 |
| *Notropis volucellus* | 0 | 0.770 | 0.007 | 0.169 | 0.054 | 0.000 |
| *Phoxinus eos* | 0 | 0.956 | 0.001 | 0.005 | 0.038 | 0.000 |
| **Phoxinus erythrogaster* | 3 | 0.592 | 0.001 | 0.009 | 0.398 | 0.000 |
| *Phoxinus neogaeus* | 0 | 0.632 | 0.001 | 0.131 | 0.236 | 0.000 |
| *Pimephales notatus* | 0 | 0.608 | 0.002 | 0.005 | 0.385 | 0.000 |
| *Pimephales promelas* | 0 | 0.559 | 0.001 | 0.004 | 0.435 | 0.000 |
| *Pimephales vigilax* | 0 | 0.932 | 0.002 | 0.007 | 0.058 | 0.000 |
| *Rhinichthys atratulus* | 0 | 0.963 | 0.000 | 0.009 | 0.027 | 0.000 |
| *Rhinichthys cataractae* | 0 | 0.965 | 0.001 | 0.018 | 0.016 | 0.000 |
| *Semotilus atromaculatus* | 0 | 0.510 | 0.000 | 0.117 | 0.373 | 0.000 |
| *Semotilus corporalis* | 0 | 0.816 | 0.004 | 0.056 | 0.122 | 0.002 |
| *Carpiodes cyprinus* | 0 | 0.496 | 0.001 | 0.332 | 0.122 | 0.049 |
| **Catostomus catostomus* | 3 | 0.652 | 0.009 | 0.064 | 0.275 | 0.000 |
| *Catostomus commersoni* | 0 | 0.764 | 0.000 | 0.035 | 0.125 | 0.076 |
| *Erimyzon oblongus* | 3 | 0.474 | 0.006 | 0.029 | 0.490 | 0.000 |
| *Erimyzon sucetta* | 2 | 0.157 | 0.004 | 0.746 | 0.093 | 0.000 |
| **Hypentelium nigricans* | 0 | 0.231 | 0.031 | 0.110 | 0.628 | 0.000 |
| *Ictiobus cyprinellus* | 1 | 0.056 | 0.863 | 0.074 | 0.004 | 0.002 |

| Appx. N cont. Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Ictiobus niger* | 2 | 0.044 | 0.048 | 0.472 | 0.436 | 0.000 |
| **Lagochila lacera* | 4 | 0.713 | 0.036 | 0.110 | 0.043 | 0.098 |
| **Minytrema melanops* | 2 | 0.455 | 0.006 | 0.300 | 0.238 | 0.001 |
| *Moxostoma anisurum* | 0 | 0.846 | 0.002 | 0.128 | 0.020 | 0.005 |
| *Moxostoma carinatum* | 3 | 0.479 | 0.000 | 0.009 | 0.510 | 0.002 |
| **Moxostoma duquesnei* | 2 | 0.360 | 0.094 | 0.304 | 0.240 | 0.001 |
| **Moxostoma erythrurum* | 1 | 0.346 | 0.214 | 0.325 | 0.114 | 0.000 |
| **Moxostoma hubbsi* | 0 | 0.151 | 0.139 | 0.656 | 0.052 | 0.001 |
| *Moxostoma macrolepidotum* | 0 | 0.982 | 0.000 | 0.011 | 0.007 | 0.000 |
| **Moxostoma valenciennesi* | 3 | 0.400 | 0.023 | 0.232 | 0.260 | 0.084 |
| *Ameiurus catus* | 0 | 0.985 | 0.000 | 0.009 | 0.006 | 0.000 |
| **Ameiurus melas* | 1 | 0.595 | 0.003 | 0.115 | 0.286 | 0.000 |
| *Ameiurus natalis* | 0 | 0.900 | 0.001 | 0.025 | 0.051 | 0.022 |
| *Ameiurus nebulosus* | 0 | 0.894 | 0.005 | 0.089 | 0.010 | 0.002 |
| *Ictalurus punctatus* | 0 | 0.920 | 0.002 | 0.011 | 0.067 | 0.000 |
| *Noturus flavus* | 0 | 0.514 | 0.001 | 0.020 | 0.465 | 0.000 |
| *Noturus gyrinus* | 0 | 0.555 | 0.001 | 0.147 | 0.297 | 0.001 |
| *Noturus insignis* | 3 | 0.041 | 0.014 | 0.016 | 0.928 | 0.000 |
| *Noturus miurus* | 2 | 0.024 | 0.000 | 0.968 | 0.008 | 0.000 |
| **Pylodictis olivaris* | 0 | 0.269 | 0.114 | 0.112 | 0.504 | 0.000 |
| **Esox americanus vermiculatus* | 1 | 0.670 | 0.004 | 0.137 | 0.189 | 0.000 |
| *Esox lucius* | 0 | 0.542 | 0.016 | 0.151 | 0.291 | 0.000 |
| **Esox masquinongy* | 2 | 0.728 | 0.015 | 0.205 | 0.050 | 0.001 |
| *Esox niger* | 0 | 0.588 | 0.010 | 0.119 | 0.282 | 0.000 |
| *Umbra limi* | 0 | 0.827 | 0.001 | 0.059 | 0.112 | 0.000 |
| **Coregonus artedi* | 3 | 0.707 | 0.047 | 0.155 | 0.082 | 0.010 |
| *Coregonus clupeaformis* | 1 | 0.026 | 0.947 | 0.002 | 0.024 | 0.000 |
| *Coregonus hoyi* | 1 | 0.013 | 0.725 | 0.027 | 0.006 | 0.229 |
| *Coregonus kiyi* | 1 | 0.016 | 0.778 | 0.023 | 0.006 | 0.176 |
| **Coregonus nigripinnis* | 4 | 0.014 | 0.826 | 0.023 | 0.006 | 0.131 |
| **Coregonus zenithicus* | 2 | 0.010 | 0.383 | 0.035 | 0.006 | 0.566 |
| *Prosopium coulteri* | 1 | 0.103 | 0.569 | 0.155 | 0.173 | 0.000 |
| *Prosopium cylindraceum* | 3 | 0.295 | 0.033 | 0.052 | 0.620 | 0.000 |
| *Salmo salar* | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| **Salvelinus fontinalis* | 2 | 0.928 | 0.001 | 0.056 | 0.008 | 0.008 |

| Appx. N cont. | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| *Salvelinus namaycush | 1 | 0.249 | 0.248 | 0.088 | 0.414 | 0.000 |
| *Thymallus arcticus | 4 | 0.781 | 0.000 | 0.124 | 0.043 | 0.051 |
| Percopsis omiscomaycus | 0 | 0.974 | 0.000 | 0.011 | 0.015 | 0.000 |
| Aphredoderus sayanus | 3 | 0.299 | 0.000 | 0.058 | 0.643 | 0.000 |
| *Lota lota | 2 | 0.780 | 0.003 | 0.163 | 0.045 | 0.010 |
| *Fundulus diaphanus | 3 | 0.606 | 0.004 | 0.157 | 0.233 | 0.000 |
| Fundulus heteroclitus | 0 | 0.947 | 0.000 | 0.011 | 0.042 | 0.000 |
| Fundulus notatus | 2 | 0.260 | 0.001 | 0.692 | 0.047 | 0.000 |
| Labidesthes sicculus | 0 | 0.502 | 0.000 | 0.457 | 0.041 | 0.000 |
| Culaea inconstans | 0 | 0.616 | 0.000 | 0.105 | 0.279 | 0.000 |
| Gasterosteus aculeatus | 0 | 0.810 | 0.143 | 0.010 | 0.037 | 0.000 |
| Pungitius pungitius | 0 | 0.948 | 0.031 | 0.003 | 0.018 | 0.000 |
| Cottus bairdi | 0 | 0.970 | 0.001 | 0.003 | 0.026 | 0.000 |
| Cottus cognatus | 0 | 0.935 | 0.001 | 0.007 | 0.057 | 0.000 |
| Cottus ricei | 3 | 0.184 | 0.000 | 0.100 | 0.715 | 0.000 |
| Myoxocephalus thompsoni | 3 | 0.034 | 0.017 | 0.237 | 0.712 | 0.000 |
| Morone chrysops | 0 | 0.939 | 0.000 | 0.002 | 0.058 | 0.001 |
| Ambloplites rupestris | 0 | 0.969 | 0.001 | 0.012 | 0.018 | 0.000 |
| Enneacanthus gloriosus | 0 | 0.785 | 0.002 | 0.184 | 0.029 | 0.001 |
| Lepomis cyanellus | 0 | 0.961 | 0.004 | 0.028 | 0.007 | 0.000 |
| Lepomis gibbosus | 0 | 0.681 | 0.048 | 0.244 | 0.027 | 0.000 |
| *Lepomis gulosus | 3 | 0.743 | 0.002 | 0.171 | 0.084 | 0.000 |
| *Lepomis humilis | 1 | 0.888 | 0.023 | 0.048 | 0.041 | 0.000 |
| Lepomis macrochirus | 0 | 0.735 | 0.000 | 0.017 | 0.247 | 0.000 |
| *Lepomis megalotis | 2 | 0.477 | 0.012 | 0.192 | 0.319 | 0.000 |
| Lepomis microlophus | 0 | 0.487 | 0.001 | 0.195 | 0.020 | 0.297 |
| Micropterus dolomieu | 0 | 0.873 | 0.001 | 0.023 | 0.104 | 0.000 |
| Micropterus salmoides | 0 | 0.844 | 0.000 | 0.049 | 0.107 | 0.000 |
| Pomoxis annularis | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| Pomoxis nigromaculatus | 0 | 0.944 | 0.010 | 0.010 | 0.037 | 0.000 |
| Ammocrypta clara | 0 | 0.521 | 0.032 | 0.049 | 0.398 | 0.000 |
| Ammocrypta pellucida | 3 | 0.366 | 0.002 | 0.020 | 0.612 | 0.000 |
| Etheostoma blennioides | 1 | 0.001 | 0.995 | 0.000 | 0.004 | 0.000 |
| *Etheostoma caeruleum | 0 | 0.455 | 0.001 | 0.052 | 0.492 | 0.000 |
| Etheostoma chlorosomum | 3 | 0.253 | 0.001 | 0.244 | 0.502 | 0.000 |

| *Appx. N cont.* | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| **Etheostoma exile* | 3 | 0.221 | 0.522 | 0.025 | 0.232 | 0.000 |
| *Etheostoma flabellare* | 0 | 0.664 | 0.006 | 0.111 | 0.218 | 0.000 |
| *Etheostoma microperca* | 1 | 0.130 | 0.798 | 0.017 | 0.055 | 0.000 |
| *Etheostoma nigrum* | 0 | 0.883 | 0.004 | 0.059 | 0.053 | 0.000 |
| *Etheostoma olmstedi* | 0 | 0.753 | 0.030 | 0.069 | 0.148 | 0.000 |
| *Etheostoma spectabile* | 0 | 0.533 | 0.002 | 0.047 | 0.418 | 0.000 |
| *Etheostoma zonale* | 0 | 0.753 | 0.025 | 0.192 | 0.030 | 0.000 |
| *Perca flavescens* | 0 | 0.529 | 0.003 | 0.109 | 0.359 | 0.000 |
| *Percina caprodes* | 0 | 0.560 | 0.000 | 0.233 | 0.204 | 0.003 |
| *Percina copelandi* | 3 | 0.147 | 0.000 | 0.009 | 0.844 | 0.000 |
| **Percina evides* | 0 | 0.100 | 0.000 | 0.033 | 0.867 | 0.000 |
| *Percina maculata* | 0 | 0.865 | 0.001 | 0.099 | 0.034 | 0.002 |
| *Percina phoxocephala* | 0 | 0.910 | 0.001 | 0.009 | 0.080 | 0.000 |
| **Percina shumardi* | 3 | 0.482 | 0.055 | 0.020 | 0.444 | 0.000 |
| *Stizostedion canadense* | 0 | 0.733 | 0.001 | 0.020 | 0.221 | 0.025 |
| *Stizostedion vitreum* | 0 | 0.862 | 0.002 | 0.034 | 0.024 | 0.079 |
| *Aplodinotus grunniens* | 0 | 0.670 | 0.000 | 0.007 | 0.323 | 0.000 |

Appendix O. Summary of stepwise discriminant function analysis with grouping variable STATUS3. Twenty-seven independent variables were entered in the model.

| Variables | Step | F to entr/rem | df 1 | df 2 | *p*-level |
|---|---|---|---|---|---|
| STREAM -(E) | 1 | 7.697 | 4 | 148 | 0.000 |
| PA -(E) | 2 | 4.029 | 4 | 147 | 0.004 |
| RAPIDS -(E) | 3 | 2.532 | 4 | 146 | 0.043 |
| DEPTH5-(E) | 4 | 2.833 | 4 | 145 | 0.027 |
| HARD_PAN-(E) | 5 | 2.612 | 4 | 144 | 0.038 |
| BALON_GU-(E) | 6 | 2.228 | 4 | 143 | 0.069 |
| BEDRKS -(E) | 7 | 2.039 | 4 | 142 | 0.092 |
| NO -(E) | 8 | 1.890 | 4 | 141 | 0.115 |
| VALUE -(E) | 9 | 1.789 | 4 | 140 | 0.134 |
| VEGETANS-(E) | 10 | 1.975 | 4 | 139 | 0.102 |
| ALGAEA -(E) | 11 | 1.764 | 4 | 138 | 0.140 |
| REPLENL-(E) | 12 | 1.770 | 4 | 137 | 0.138 |
| MAXAGEL-(E) | 13 | 3.409 | 4 | 136 | 0.011 |
| FI2 -(E) | 14 | 2.062 | 4 | 135 | 0.089 |
| DEPTH4-(E) | 15 | 1.801 | 4 | 134 | 0.132 |
| TURBIDYA-(E) | 16 | 1.769 | 4 | 133 | 0.139 |
| PU -(E) | 17 | 1.527 | 4 | 132 | 0.198 |
| SO -(E) | 18 | 1.550 | 4 | 131 | 0.192 |
| DEPTH2-(E) | 19 | 1.241 | 4 | 130 | 0.297 |
| OVERHEDS-(E) | 20 | 1.138 | 4 | 129 | 0.342 |
| PH -(E) | 21 | 1.085 | 4 | 128 | 0.367 |
| SUBSTRTA-(E) | 22 | 1.034 | 4 | 127 | 0.393 |
| OVERHEDA-(E) | 23 | 1.079 | 4 | 126 | 0.370 |
| RAPIDA -(E) | 24 | 1.039 | 4 | 125 | 0.390 |
| RUBBLE -(E) | 25 | 1.026 | 4 | 124 | 0.396 |
| VEGETANA-(E) | 26 | 1.164 | 4 | 123 | 0.330 |
| LAKE -(E) | 27 | 1.178 | 4 | 122 | 0.324 |

*Appx. O cont.*

| Variables | No. of vars. in | F-value | df 1 | df 2 | *p*-level |
|---|---|---|---|---|---|
| STREAM -(E) | 1 | 7.697 | 4 | 148.000 | 0.000 |
| PA -(E) | 2 | 5.799 | 8 | 294.000 | 0.000 |
| RAPIDS -(E) | 3 | 4.697 | 12 | 386.571 | 0.000 |
| DEPTH5-(E) | 4 | 4.246 | 16 | 443.620 | 0.000 |
| HARD_PAN-(E) | 5 | 3.938 | 20 | 478.544 | 0.000 |
| BALON_GU-(E) | 6 | 3.669 | 24 | 500.077 | 0.000 |
| BEDRKS -(E) | 7 | 3.451 | 28 | 513.410 | 0.000 |
| NO -(E) | 8 | 3.268 | 32 | 521.578 | 0.000 |
| VALUE -(E) | 9 | 3.115 | 36 | 526.382 | 0.000 |
| VEGETANS-(E) | 10 | 3.016 | 40 | 528.927 | 0.000 |
| ALGAEA -(E) | 11 | 2.914 | 44 | 529.908 | 0.000 |
| REPLENL-(E) | 12 | 2.830 | 48 | 529.777 | 0.000 |
| MAXAGEL-(E) | 13 | 2.911 | 52 | 528.837 | 0.000 |
| FI2 -(E) | 14 | 2.868 | 56 | 527.294 | 0.000 |
| DEPTH4-(E) | 15 | 2.810 | 60 | 525.297 | 0.000 |
| TURBIDYA-(E) | 16 | 2.757 | 64 | 522.948 | 0.000 |
| PU -(E) | 17 | 2.694 | 68 | 520.324 | 0.000 |
| SO -(E) | 18 | 2.639 | 72 | 517.483 | 0.000 |
| DEPTH2-(E) | 19 | 2.569 | 76 | 514.467 | 0.000 |
| OVERHEDS-(E) | 20 | 2.499 | 80 | 511.310 | 0.000 |
| PH -(E) | 21 | 2.433 | 84 | 508.037 | 0.000 |
| SUBSTRTA-(E) | 22 | 2.369 | 88 | 504.668 | 0.000 |
| OVERHEDA-(E) | 23 | 2.314 | 92 | 501.220 | 0.000 |
| RAPIDA -(E) | 24 | 2.261 | 96 | 497.704 | 0.000 |
| RUBBLE -(E) | 25 | 2.211 | 100 | 494.132 | 0.000 |
| VEGETANA-(E) | 26 | 2.173 | 104 | 490.511 | 0.000 |
| LAKE -(E) | 27 | 2.139 | 108 | 486.849 | 0.000 |

Appendix P. Conservation ranks for Great Lakes fishes determined from the discriminant function analysis of STATUS4. Species were re-classified to the rank with the largest predicted value to one of five possible ranks (0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated). Incorrectly ranked species are marked with an asterisk (*).

| Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Ichthyomyzon castaneus* | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| *Ichthyomyzon fossor* | 3 | 0.006 | 0.286 | 0.002 | 0.706 | 0.000 |
| *Ichthyomyzon unicuspis* | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| *Lampetra appendix* | 1 | 0.027 | 0.727 | 0.000 | 0.245 | 0.000 |
| *Acipenser fulvescens* | 3 | 0.222 | 0.242 | 0.001 | 0.536 | 0.000 |
| *Polyodon spathula* | 2 | 0.117 | 0.005 | 0.805 | 0.005 | 0.068 |
| *Lepisosteus oculatus* | 3 | 0.256 | 0.207 | 0.041 | 0.496 | 0.000 |
| *Lepisosteus osseus* | 0 | 0.805 | 0.014 | 0.020 | 0.162 | 0.000 |
| **Amia calva* | 0 | 0.256 | 0.151 | 0.543 | 0.050 | 0.000 |
| *Hiodon tergisus* | 2 | 0.266 | 0.006 | 0.639 | 0.089 | 0.000 |
| *Anguilla rostrata* | 1 | 0.164 | 0.664 | 0.003 | 0.168 | 0.000 |
| *Alosa pseudoharengus* | 0 | 0.624 | 0.000 | 0.365 | 0.002 | 0.009 |
| *Alosa sapidissima* | 4 | 0.060 | 0.001 | 0.006 | 0.001 | 0.931 |
| *Dorosoma cepedianum* | 0 | 0.948 | 0.001 | 0.033 | 0.019 | 0.000 |
| **Campostoma anomalum* | 1 | 0.724 | 0.220 | 0.017 | 0.039 | 0.001 |
| *Campostoma oligolepis* | 0 | 0.993 | 0.001 | 0.002 | 0.004 | 0.000 |
| *Clinostomus elongatus* | 3 | 0.190 | 0.004 | 0.079 | 0.728 | 0.000 |
| *Couesius plumbeus* | 0 | 0.944 | 0.000 | 0.003 | 0.053 | 0.000 |
| *Cyprinella analostana* | 0 | 0.992 | 0.000 | 0.006 | 0.001 | 0.000 |
| *Cyprinella spiloptera* | 0 | 0.966 | 0.000 | 0.028 | 0.006 | 0.000 |
| *Erimystax x-punctatus* | 3 | 0.053 | 0.004 | 0.001 | 0.941 | 0.000 |
| **Exoglossum laurae* | 2 | 0.120 | 0.009 | 0.126 | 0.744 | 0.000 |
| **Exoglossum maxilingua* | 3 | 0.116 | 0.000 | 0.458 | 0.426 | 0.000 |
| *Hybognathus hankinsoni* | 0 | 0.983 | 0.001 | 0.013 | 0.004 | 0.000 |
| *Hybognathus regius* | 2 | 0.034 | 0.001 | 0.885 | 0.080 | 0.000 |
| *Luxilis chrysocephalus* | 3 | 0.106 | 0.016 | 0.049 | 0.829 | 0.000 |
| **Luxilis cornutus* | 0 | 0.418 | 0.033 | 0.057 | 0.491 | 0.000 |
| **Lythrurus umbratilis* | 2 | 0.834 | 0.001 | 0.149 | 0.016 | 0.000 |
| *Macrhybopsis storeriana* | 1 | 0.345 | 0.473 | 0.026 | 0.155 | 0.000 |
| *Margariscus margarita* | 0 | 0.511 | 0.007 | 0.032 | 0.450 | 0.000 |
| *Nocomis biguttatus* | 0 | 0.906 | 0.003 | 0.060 | 0.031 | 0.000 |
| *Nocomis micropogon* | 3 | 0.104 | 0.039 | 0.025 | 0.831 | 0.000 |

| *Appx. P cont.* | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| *Lagochila lacera* | 4 | 0.017 | 0.000 | 0.000 | 0.002 | 0.980 |
| *Minytrema melanops* | 2 | 0.152 | 0.052 | 0.791 | 0.004 | 0.000 |
| *Moxostoma anisurum* | 0 | 0.853 | 0.012 | 0.087 | 0.046 | 0.001 |
| *Moxostoma carinatum* | 2 | 0.059 | 0.001 | 0.940 | 0.001 | 0.000 |
| *Moxostoma duquesnei* | 1 | 0.196 | 0.509 | 0.015 | 0.276 | 0.004 |
| *Moxostoma erythrurum* | 1 | 0.024 | 0.936 | 0.003 | 0.038 | 0.000 |
| **Moxostoma hubbsi* | 0 | 0.078 | 0.416 | 0.486 | 0.020 | 0.000 |
| *Moxostoma macrolepidotum* | 0 | 0.997 | 0.000 | 0.002 | 0.002 | 0.000 |
| *Moxostoma valenciennesi* | 3 | 0.117 | 0.036 | 0.026 | 0.501 | 0.319 |
| *Ameiurus catus* | 0 | 0.998 | 0.000 | 0.002 | 0.000 | 0.000 |
| **Ameiurus melas* | 1 | 0.799 | 0.032 | 0.126 | 0.043 | 0.000 |
| *Ameiurus natalis* | 0 | 0.902 | 0.057 | 0.002 | 0.037 | 0.001 |
| *Ameiurus nebulosus* | 0 | 0.923 | 0.002 | 0.072 | 0.003 | 0.000 |
| *Ictalurus punctatus* | 0 | 0.982 | 0.000 | 0.002 | 0.016 | 0.000 |
| **Noturus flavus* | 0 | 0.428 | 0.007 | 0.006 | 0.559 | 0.000 |
| *Noturus gyrinus* | 0 | 0.786 | 0.002 | 0.210 | 0.002 | 0.000 |
| *Noturus insignis* | 3 | 0.052 | 0.059 | 0.180 | 0.709 | 0.000 |
| *Noturus miurus* | 2 | 0.012 | 0.000 | 0.986 | 0.002 | 0.000 |
| **Pylodictis olivaris* | 0 | 0.324 | 0.356 | 0.034 | 0.286 | 0.000 |
| **Esox americanus vermiculatus* | 1 | 0.950 | 0.001 | 0.028 | 0.020 | 0.000 |
| *Esox lucius* | 0 | 0.801 | 0.040 | 0.029 | 0.130 | 0.000 |
| **Esox masquinongy* | 2 | 0.700 | 0.002 | 0.293 | 0.005 | 0.000 |
| *Esox niger* | 0 | 0.955 | 0.025 | 0.010 | 0.009 | 0.000 |
| *Umbra limi* | 0 | 0.863 | 0.003 | 0.090 | 0.044 | 0.000 |
| **Coregonus artedi* | 3 | 0.226 | 0.378 | 0.388 | 0.008 | 0.000 |
| *Coregonus clupeaformis* | 1 | 0.021 | 0.858 | 0.000 | 0.120 | 0.000 |
| *Coregonus hoyi* | 1 | 0.010 | 0.835 | 0.040 | 0.028 | 0.088 |
| *Coregonus kiyi* | 1 | 0.013 | 0.704 | 0.026 | 0.028 | 0.230 |
| **Coregonus nigripinnis* | 4 | 0.005 | 0.934 | 0.017 | 0.011 | 0.033 |
| *Coregonus zenithicus* | 2 | 0.067 | 0.048 | 0.751 | 0.009 | 0.125 |
| *Prosopium coulteri* | 1 | 0.003 | 0.984 | 0.000 | 0.012 | 0.000 |
| *Prosopium cylindraceum* | 3 | 0.010 | 0.002 | 0.000 | 0.987 | 0.000 |
| *Salmo salar* | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| **Salvelinus fontinalis* | 2 | 0.725 | 0.001 | 0.260 | 0.004 | 0.011 |
| *Salvelinus namaycush* | 1 | 0.078 | 0.514 | 0.023 | 0.384 | 0.000 |

| Appx. P cont. | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| *Thymallus arcticus* | 4 | 0.012 | 0.000 | 0.001 | 0.002 | 0.985 |
| *Percopsis omiscomaycus* | 0 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Aphredoderus sayanus* | 1 | 0.409 | 0.383 | 0.071 | 0.138 | 0.000 |
| **Lota lota* | 2 | 0.881 | 0.015 | 0.095 | 0.007 | 0.001 |
| *Fundulus diaphanus* | 1 | 0.203 | 0.552 | 0.129 | 0.116 | 0.000 |
| *Fundulus heteroclitus* | 0 | 0.976 | 0.002 | 0.008 | 0.015 | 0.000 |
| **Fundulus notatus* | 2 | 0.498 | 0.031 | 0.264 | 0.205 | 0.001 |
| *Labidesthes sicculus* | 0 | 0.845 | 0.000 | 0.151 | 0.004 | 0.000 |
| *Culaea inconstans* | 0 | 0.734 | 0.009 | 0.003 | 0.254 | 0.000 |
| *Gasterosteus aculeatus* | 0 | 0.864 | 0.132 | 0.000 | 0.003 | 0.000 |
| *Pungitius pungitius* | 0 | 0.894 | 0.094 | 0.006 | 0.006 | 0.000 |
| *Cottus bairdi* | 0 | 0.991 | 0.001 | 0.002 | 0.006 | 0.000 |
| *Cottus cognatus* | 0 | 0.892 | 0.037 | 0.001 | 0.069 | 0.000 |
| *Myoxocephalus thompsoni* | 3 | 0.121 | 0.050 | 0.001 | 0.828 | 0.000 |
| *Morone chrysops* | 0 | 0.949 | 0.000 | 0.046 | 0.004 | 0.000 |
| *Ambloplites rupestris* | 0 | 0.977 | 0.015 | 0.001 | 0.007 | 0.000 |
| *Enneacanthus gloriosus* | 0 | 0.950 | 0.001 | 0.047 | 0.003 | 0.000 |
| *Lepomis cyanellus* | 0 | 0.967 | 0.002 | 0.023 | 0.008 | 0.000 |
| *Lepomis gibbosus* | 0 | 0.918 | 0.068 | 0.002 | 0.013 | 0.000 |
| **Lepomis gulosus* | 3 | 0.935 | 0.002 | 0.045 | 0.018 | 0.000 |
| **Lepomis humilis* | 1 | 0.746 | 0.246 | 0.001 | 0.006 | 0.000 |
| *Lepomis macrochirus* | 0 | 0.902 | 0.004 | 0.040 | 0.055 | 0.000 |
| *Lepomis megalotis* | 2 | 0.364 | 0.017 | 0.488 | 0.132 | 0.000 |
| *Lepomis microlophus* | 0 | 0.684 | 0.000 | 0.309 | 0.005 | 0.002 |
| *Micropterus dolomieu* | 0 | 0.860 | 0.000 | 0.107 | 0.033 | 0.000 |
| *Micropterus salmoides* | 0 | 0.931 | 0.001 | 0.002 | 0.066 | 0.000 |
| *Pomoxis annularis* | 1 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| *Pomoxis nigromaculatus* | 0 | 0.931 | 0.002 | 0.017 | 0.048 | 0.002 |
| *Ammocrypta clara* | 0 | 0.780 | 0.051 | 0.165 | 0.004 | 0.000 |
| *Ammocrypta pellucida* | 2 | 0.202 | 0.001 | 0.794 | 0.003 | 0.000 |
| *Etheostoma blennioides* | 1 | 0.001 | 0.916 | 0.000 | 0.083 | 0.000 |
| *Etheostoma caeruleum* | 0 | 0.728 | 0.001 | 0.029 | 0.241 | 0.000 |
| *Etheostoma chlorosomum* | 3 | 0.089 | 0.008 | 0.031 | 0.872 | 0.000 |
| **Etheostoma exile* | 3 | 0.338 | 0.341 | 0.002 | 0.320 | 0.000 |
| *Etheostoma flabellare* | 0 | 0.829 | 0.044 | 0.006 | 0.120 | 0.000 |
| *Etheostoma microperca* | 1 | 0.015 | 0.979 | 0.001 | 0.004 | 0.000 |

| *Appx. P cont.* | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| *Etheostoma nigrum* | 0 | 0.965 | 0.001 | 0.014 | 0.020 | 0.000 |
| *Etheostoma olmstedi* | 0 | 0.929 | 0.002 | 0.060 | 0.008 | 0.000 |
| *Etheostoma spectabile* | 0 | 0.595 | 0.004 | 0.027 | 0.374 | 0.000 |
| *Etheostoma zonale* | 0 | 0.964 | 0.013 | 0.002 | 0.021 | 0.000 |
| *Perca flavescens* | 0 | 0.734 | 0.193 | 0.043 | 0.031 | 0.000 |
| **Percina caprodes* | 0 | 0.486 | 0.004 | 0.502 | 0.007 | 0.000 |
| **Percina copelandi* | 2 | 0.639 | 0.001 | 0.254 | 0.107 | 0.000 |
| *Percina evides* | 0 | 0.558 | 0.004 | 0.234 | 0.204 | 0.000 |
| *Percina maculata* | 0 | 0.940 | 0.005 | 0.050 | 0.005 | 0.000 |
| *Percina phoxocephala* | 0 | 0.986 | 0.000 | 0.002 | 0.012 | 0.000 |
| **Percina shumardi* | 3 | 0.545 | 0.007 | 0.163 | 0.286 | 0.000 |
| *Stizostedion canadense* | 0 | 0.877 | 0.003 | 0.010 | 0.110 | 0.000 |
| **Stizostedion vitreum* | 0 | 0.270 | 0.016 | 0.001 | 0.048 | 0.665 |
| *Aplodinotus grunniens* | 0 | 0.806 | 0.006 | 0.038 | 0.149 | 0.000 |

Appendix Q. Conservation ranks for Great Lakes fishes determined by the stepwise discriminant function analysis of STATUS4. Species were re-classified to the rank with the largest predicted value to one of five possible ranks (0 = not-at-risk, 1 = special concern, 2 = threatened, 3 = endangered, 4 = extirpated). Incorrectly ranked species are marked with an asterisk (*).

| | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| *Ichthyomyzon castaneus* | 1 | 0.001 | 0.999 | 0.000 | 0.000 | 0.000 |
| **Ichthyomyzon fossor* | 3 | 0.171 | 0.427 | 0.018 | 0.382 | 0.002 |
| *Ichthyomyzon unicuspis* | 1 | 0.000 | 0.999 | 0.000 | 0.001 | 0.000 |
| *Lampetra appendix* | 1 | 0.320 | 0.397 | 0.058 | 0.220 | 0.006 |
| *Acipenser fulvescens* | 3 | 0.162 | 0.192 | 0.001 | 0.639 | 0.007 |
| **Polyodon spathula* | 2 | 0.006 | 0.000 | 0.261 | 0.001 | 0.732 |
| **Lepisosteus oculatus* | 3 | 0.382 | 0.135 | 0.168 | 0.314 | 0.000 |
| *Lepisosteus osseus* | 0 | 0.573 | 0.056 | 0.030 | 0.342 | 0.000 |
| *Amia calva* | 0 | 0.387 | 0.332 | 0.119 | 0.162 | 0.000 |
| **Hiodon tergisus* | 2 | 0.543 | 0.007 | 0.312 | 0.138 | 0.000 |
| **Anguilla rostrata* | 1 | 0.696 | 0.186 | 0.026 | 0.093 | 0.000 |
| *Alosa pseudoharengus* | 0 | 0.633 | 0.027 | 0.277 | 0.057 | 0.006 |
| *Alosa sapidissima* | 4 | 0.159 | 0.091 | 0.075 | 0.035 | 0.640 |
| *Dorosoma cepedianum* | 0 | 0.864 | 0.035 | 0.059 | 0.041 | 0.000 |
| **Campostoma anomalum* | 1 | 0.332 | 0.252 | 0.088 | 0.327 | 0.002 |
| *Campostoma oligolepis* | 0 | 0.783 | 0.002 | 0.103 | 0.112 | 0.000 |
| *Clinostomus elongatus* | 3 | 0.148 | 0.048 | 0.061 | 0.743 | 0.000 |
| *Couesius plumbeus* | 0 | 0.837 | 0.005 | 0.029 | 0.129 | 0.000 |
| *Cyprinella analostana* | 0 | 0.834 | 0.010 | 0.111 | 0.044 | 0.000 |
| *Cyprinella spiloptera* | 0 | 0.779 | 0.010 | 0.150 | 0.061 | 0.001 |
| *Erimystax x-punctatus* | 3 | 0.143 | 0.002 | 0.011 | 0.844 | 0.000 |
| **Exoglossum laurae* | 2 | 0.484 | 0.024 | 0.222 | 0.263 | 0.007 |
| *Exoglossum maxilingua* | 3 | 0.406 | 0.002 | 0.055 | 0.536 | 0.000 |
| *Hybognathus hankinsoni* | 0 | 0.959 | 0.002 | 0.029 | 0.010 | 0.000 |
| **Hybognathus regius* | 2 | 0.367 | 0.022 | 0.319 | 0.292 | 0.000 |

| *Appx. Q cont.* | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| **Luxilis chrysocephalus* | 3 | 0.611 | 0.021 | 0.086 | 0.281 | 0.000 |
| *Luxilis cornutus* | 0 | 0.469 | 0.107 | 0.128 | 0.295 | 0.000 |
| **Lythrurus umbratilis* | 2 | 0.803 | 0.021 | 0.066 | 0.110 | 0.000 |
| **Macrhybopsis storeriana* | 1 | 0.331 | 0.177 | 0.359 | 0.133 | 0.000 |
| **Margariscus margarita* | 0 | 0.271 | 0.022 | 0.142 | 0.563 | 0.002 |
| *Nocomis biguttatus* | 0 | 0.959 | 0.008 | 0.021 | 0.012 | 0.001 |
| *Nocomis micropogon* | 3 | 0.360 | 0.017 | 0.107 | 0.515 | 0.001 |
| *Notemigonus crysoleucas* | 0 | 0.502 | 0.183 | 0.261 | 0.051 | 0.003 |
| *Notropis amblops* | 4 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |
| **Notropis ariommus* | 0 | 0.334 | 0.036 | 0.117 | 0.512 | 0.000 |
| *Notropis atherinoides* | 0 | 0.509 | 0.108 | 0.013 | 0.369 | 0.000 |
| **Notropis bifrenatus* | 2 | 0.747 | 0.008 | 0.240 | 0.004 | 0.001 |
| *Notropis blennius* | 0 | 0.593 | 0.011 | 0.045 | 0.351 | 0.000 |
| **Notropis boops* | 0 | 0.263 | 0.076 | 0.077 | 0.584 | 0.000 |
| *Notropis buccatus* | 0 | 0.726 | 0.036 | 0.174 | 0.061 | 0.001 |
| *Notropis buchanani* | 0 | 0.869 | 0.015 | 0.040 | 0.076 | 0.000 |
| *Notropis chalybaeus* | 0 | 0.475 | 0.040 | 0.230 | 0.255 | 0.000 |
| **Notropis dorsalis* | 2 | 0.837 | 0.001 | 0.059 | 0.102 | 0.000 |
| **Notropis heterodon* | 3 | 0.738 | 0.004 | 0.027 | 0.231 | 0.000 |
| **Notropis heterolepis* | 3 | 0.808 | 0.021 | 0.070 | 0.101 | 0.000 |
| *Notropis hudsonius* | 0 | 0.748 | 0.004 | 0.135 | 0.113 | 0.000 |
| *Notropis photogenis* | 3 | 0.280 | 0.043 | 0.067 | 0.609 | 0.001 |
| *Notropis procne* | 0 | 0.849 | 0.002 | 0.028 | 0.121 | 0.000 |
| *Notropis rubellus* | 0 | 0.939 | 0.002 | 0.037 | 0.022 | 0.000 |
| *Notropis stramineus* | 0 | 0.781 | 0.020 | 0.045 | 0.154 | 0.000 |
| **Notropis texanus* | 3 | 0.676 | 0.001 | 0.019 | 0.304 | 0.000 |
| *Notropis volucellus* | 0 | 0.766 | 0.053 | 0.137 | 0.044 | 0.000 |
| **Phenacobius mirabilis* | 0 | 0.191 | 0.063 | 0.721 | 0.025 | 0.000 |
| *Phoxinus eos* | 0 | 0.954 | 0.008 | 0.008 | 0.030 | 0.000 |
| **Phoxinus erythrogaster* | 3 | 0.644 | 0.005 | 0.008 | 0.343 | 0.000 |
| *Phoxinus neogaeus* | 0 | 0.648 | 0.030 | 0.019 | 0.303 | 0.000 |
| *Pimephales notatus* | 0 | 0.737 | 0.002 | 0.061 | 0.200 | 0.000 |
| *Pimephales promelas* | 0 | 0.768 | 0.006 | 0.053 | 0.173 | 0.000 |
| *Pimephales vigilax* | 0 | 0.881 | 0.002 | 0.028 | 0.088 | 0.000 |

| Appx. Q cont. Species | Observed | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| *Rhinichthys atratulus* | 0 | 0.541 | 0.003 | 0.011 | 0.444 | 0.000 |
| *Rhinichthys cataractae* | 0 | 0.962 | 0.009 | 0.012 | 0.017 | 0.000 |
| *Semotilus atromaculatus* | 0 | 0.725 | 0.008 | 0.240 | 0.026 | 0.000 |
| *Semotilus corporalis* | 0 | 0.893 | 0.002 | 0.081 | 0.021 | 0.002 |
| *Carpiodes cyprinus* | 0 | 0.523 | 0.024 | 0.214 | 0.236 | 0.002 |
| **Catostomus catostomus* | 3 | 0.659 | 0.037 | 0.020 | 0.284 | 0.000 |
| *Catostomus commersoni* | 0 | 0.796 | 0.003 | 0.038 | 0.109 | 0.053 |
| **Erimyzon oblongus* | 3 | 0.318 | 0.134 | 0.367 | 0.179 | 0.001 |
| *Erimyzon sucetta* | 2 | 0.287 | 0.057 | 0.598 | 0.059 | 0.000 |
| **Hypentelium nigricans* | 0 | 0.308 | 0.343 | 0.130 | 0.220 | 0.000 |
| *Ictiobus cyprinellus* | 1 | 0.096 | 0.857 | 0.012 | 0.033 | 0.002 |
| *Ictiobus niger* | 1 | 0.011 | 0.931 | 0.009 | 0.050 | 0.000 |
| **Lagochila lacera* | 4 | 0.445 | 0.059 | 0.238 | 0.161 | 0.097 |
| *Minytrema melanops* | 2 | 0.181 | 0.084 | 0.648 | 0.087 | 0.001 |
| *Moxostoma anisurum* | 0 | 0.802 | 0.017 | 0.078 | 0.089 | 0.015 |
| *Moxostoma carinatum* | 2 | 0.386 | 0.008 | 0.582 | 0.023 | 0.001 |
| *Moxostoma duquesnei* | 1 | 0.176 | 0.443 | 0.163 | 0.215 | 0.004 |
| *Moxostoma erythrurum* | 1 | 0.205 | 0.416 | 0.222 | 0.152 | 0.004 |
| **Moxostoma hubbsi* | 0 | 0.078 | 0.755 | 0.105 | 0.061 | 0.000 |
| *Moxostoma macrolepidotum* | 0 | 0.904 | 0.008 | 0.030 | 0.057 | 0.000 |
| *Moxostoma valenciennesi* | 3 | 0.274 | 0.044 | 0.108 | 0.457 | 0.117 |
| *Ameiurus catus* | 0 | 0.909 | 0.010 | 0.031 | 0.049 | 0.001 |
| **Ameiurus melas* | 1 | 0.748 | 0.022 | 0.181 | 0.035 | 0.014 |
| *Ameiurus natalis* | 0 | 0.711 | 0.012 | 0.224 | 0.027 | 0.026 |
| *Ameiurus nebulosus* | 0 | 0.820 | 0.010 | 0.153 | 0.011 | 0.006 |
| *Ictalurus punctatus* | 0 | 0.824 | 0.012 | 0.050 | 0.114 | 0.000 |
| **Noturus flavus* | 0 | 0.168 | 0.044 | 0.003 | 0.784 | 0.000 |
| *Noturus gyrinus* | 0 | 0.512 | 0.007 | 0.447 | 0.033 | 0.000 |
| **Noturus insignis* | 3 | 0.546 | 0.023 | 0.245 | 0.180 | 0.006 |
| **Noturus miurus* | 2 | 0.598 | 0.052 | 0.265 | 0.083 | 0.002 |
| *Pylodictis olivaris* | 0 | 0.418 | 0.391 | 0.084 | 0.107 | 0.000 |
| **Esox americanus vermiculatus* | 1 | 0.605 | 0.046 | 0.074 | 0.275 | 0.000 |

| Appx. Q cont. | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| *Esox lucius* | 0 | 0.632 | 0.048 | 0.174 | 0.146 | 0.000 |
| **Esox masquinongy* | 2 | 0.686 | 0.025 | 0.108 | 0.181 | 0.000 |
| *Esox niger* | 0 | 0.701 | 0.025 | 0.203 | 0.072 | 0.000 |
| *Umbra limi* | 0 | 0.813 | 0.009 | 0.083 | 0.095 | 0.000 |
| **Coregonus artedi* | 3 | 0.279 | 0.478 | 0.211 | 0.020 | 0.011 |
| *Coregonus clupeaformis* | 1 | 0.224 | 0.571 | 0.003 | 0.202 | 0.000 |
| *Coregonus hoyi* | 1 | 0.036 | 0.616 | 0.107 | 0.052 | 0.189 |
| *Coregonus kiyi* | 1 | 0.047 | 0.610 | 0.112 | 0.059 | 0.172 |
| **Coregonus nigripinnis* | 4 | 0.041 | 0.666 | 0.096 | 0.058 | 0.139 |
| **Coregonus zenithicus* | 2 | 0.023 | 0.371 | 0.133 | 0.033 | 0.439 |
| *Prosopium coulteri* | 1 | 0.019 | 0.939 | 0.002 | 0.040 | 0.000 |
| *Prosopium cylindraceum* | 3 | 0.147 | 0.072 | 0.003 | 0.777 | 0.000 |
| *Salmo salar* | 4 | 0.001 | 0.000 | 0.003 | 0.000 | 0.996 |
| **Salvelinus fontinalis* | 2 | 0.881 | 0.007 | 0.047 | 0.036 | 0.030 |
| *Salvelinus namaycush* | 1 | 0.195 | 0.676 | 0.028 | 0.101 | 0.000 |
| **Thymallus arcticus* | 4 | 0.633 | 0.009 | 0.238 | 0.053 | 0.067 |
| *Percopsis omiscomaycus* | 0 | 0.865 | 0.001 | 0.088 | 0.046 | 0.000 |
| **Aphredoderus sayanus* | 1 | 0.704 | 0.047 | 0.111 | 0.138 | 0.000 |
| **Lota lota* | 2 | 0.633 | 0.026 | 0.306 | 0.010 | 0.025 |
| **Fundulus diaphanus* | 1 | 0.666 | 0.041 | 0.168 | 0.124 | 0.000 |
| *Fundulus heteroclitus* | 0 | 0.923 | 0.004 | 0.017 | 0.057 | 0.000 |
| **Fundulus notatus* | 2 | 0.561 | 0.141 | 0.132 | 0.165 | 0.001 |
| *Gambusia affinis* | 0 | 0.806 | 0.011 | 0.106 | 0.078 | 0.000 |
| **Labidesthes sicculus* | 0 | 0.354 | 0.004 | 0.609 | 0.031 | 0.002 |
| *Culaea inconstans* | 0 | 0.737 | 0.002 | 0.068 | 0.192 | 0.000 |
| *Gasterosteus aculeatus* | 0 | 0.646 | 0.317 | 0.016 | 0.022 | 0.000 |
| *Pungitius pungitius* | 0 | 0.828 | 0.092 | 0.010 | 0.070 | 0.000 |
| *Cottus bairdi* | 0 | 0.728 | 0.026 | 0.147 | 0.099 | 0.000 |
| *Cottus cognatus* | 0 | 0.759 | 0.096 | 0.052 | 0.093 | 0.000 |
| **Cottus ricei* | 1 | 0.534 | 0.183 | 0.050 | 0.234 | 0.000 |
| **Myoxocephalus thompsoni* | 3 | 0.014 | 0.869 | 0.002 | 0.114 | 0.000 |
| *Morone chrysops* | 0 | 0.857 | 0.001 | 0.126 | 0.015 | 0.001 |

| *Appx. Q cont.* | | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|
| Species | Observed | | | | | |
| *Ambloplites rupestris* | 0 | 0.968 | 0.009 | 0.011 | 0.012 | 0.000 |
| *Enneacanthus gloriosus* | 0 | 0.896 | 0.007 | 0.072 | 0.025 | 0.000 |
| *Lepomis cyanellus* | 0 | 0.958 | 0.003 | 0.009 | 0.030 | 0.000 |
| *Lepomis gibbosus* | 0 | 0.918 | 0.015 | 0.030 | 0.037 | 0.000 |
| **Lepomis gulosus* | 3 | 0.911 | 0.025 | 0.043 | 0.021 | 0.000 |
| **Lepomis humilis* | 1 | 0.815 | 0.081 | 0.074 | 0.030 | 0.000 |
| *Lepomis macrochirus* | 0 | 0.882 | 0.017 | 0.045 | 0.055 | 0.001 |
| **Lepomis megalotis* | 2 | 0.629 | 0.102 | 0.143 | 0.127 | 0.000 |
| *Lepomis microlophus* | 0 | 0.516 | 0.005 | 0.464 | 0.007 | 0.007 |
| *Micropterus dolomieu* | 0 | 0.797 | 0.002 | 0.103 | 0.098 | 0.000 |
| *Micropterus salmoides* | 0 | 0.887 | 0.006 | 0.038 | 0.069 | 0.000 |
| *Pomoxis annularis* | 1 | 0.000 | 0.999 | 0.000 | 0.000 | 0.000 |
| *Pomoxis nigromaculatus* | 0 | 0.874 | 0.010 | 0.084 | 0.028 | 0.005 |
| *Ammocrypta clara* | 0 | 0.768 | 0.022 | 0.172 | 0.038 | 0.000 |
| **Ammocrypta pellucida* | 2 | 0.609 | 0.002 | 0.380 | 0.009 | 0.000 |
| **Etheostoma blennioides* | 1 | 0.020 | 0.424 | 0.001 | 0.555 | 0.000 |
| **Etheostoma caeruleum* | 0 | 0.337 | 0.071 | 0.061 | 0.531 | 0.001 |
| *Etheostoma chlorosomum* | 3 | 0.244 | 0.063 | 0.027 | 0.665 | 0.000 |
| **Etheostoma exile* | 3 | 0.258 | 0.591 | 0.034 | 0.117 | 0.000 |
| *Etheostoma flabellare* | 0 | 0.525 | 0.032 | 0.057 | 0.384 | 0.001 |
| *Etheostoma microperca* | 1 | 0.283 | 0.575 | 0.022 | 0.121 | 0.000 |
| *Etheostoma nigrum* | 0 | 0.703 | 0.016 | 0.129 | 0.152 | 0.000 |
| *Etheostoma olmstedi* | 0 | 0.771 | 0.020 | 0.194 | 0.014 | 0.000 |
| **Etheostoma spectabile* | 0 | 0.353 | 0.068 | 0.044 | 0.534 | 0.000 |
| *Etheostoma zonale* | 0 | 0.500 | 0.113 | 0.017 | 0.370 | 0.001 |
| *Perca flavescens* | 0 | 0.734 | 0.066 | 0.032 | 0.168 | 0.000 |
| **Percina caprodes* | 0 | 0.379 | 0.005 | 0.593 | 0.019 | 0.003 |
| **Percina copelandi* | 2 | 0.677 | 0.008 | 0.208 | 0.107 | 0.000 |
| *Percina evides* | 0 | 0.579 | 0.004 | 0.334 | 0.082 | 0.000 |
| *Percina maculata* | 0 | 0.679 | 0.005 | 0.262 | 0.054 | 0.000 |
| *Percina phoxocephala* | 0 | 0.928 | 0.003 | 0.006 | 0.063 | 0.000 |
| **Percina shumardi* | 3 | 0.728 | 0.006 | 0.210 | 0.052 | 0.003 |
| *Stizostedion canadense* | 0 | 0.671 | 0.035 | 0.055 | 0.062 | 0.178 |
| **Stizostedion vitreum* | 0 | 0.462 | 0.008 | 0.025 | 0.041 | 0.464 |
| *Aplodinotus grunniens* | 0 | 0.931 | 0.001 | 0.053 | 0.015 | 0.000 |

Appendix R. Summary of stepwise discriminant function analysis with grouping variable STATUS4. Twenty-one independent variables were entered in the model.

| | Step | F to entr/rem | df 1 | df 2 | *p*-level |
|---|---|---|---|---|---|
| STREAM -(E) | 1 | 4.886 | 4 | 148 | 0.001 |
| RAPIDS -(E) | 2 | 3.378 | 4 | 147 | 0.011 |
| PA -(E) | 3 | 2.747 | 4 | 146 | 0.031 |
| DEPTH5-(E) | 4 | 2.995 | 4 | 145 | 0.021 |
| RUNS -(E) | 5 | 1.965 | 4 | 144 | 0.103 |
| VALUE -(E) | 6 | 2.019 | 4 | 143 | 0.095 |
| HARD_PAN-(E) | 7 | 2.150 | 4 | 142 | 0.078 |
| MAXAGEL-(E) | 8 | 2.131 | 4 | 141 | 0.080 |
| REPLENL-(E) | 9 | 3.282 | 4 | 140 | 0.013 |
| LAKE -(E) | 10 | 2.029 | 4 | 139 | 0.094 |
| PH -(E) | 11 | 1.459 | 4 | 138 | 0.218 |
| FI2 -(E) | 12 | 1.659 | 4 | 137 | 0.163 |
| SO -(E) | 13 | 1.646 | 4 | 136 | 0.166 |
| ALGAEA -(E) | 14 | 1.780 | 4 | 135 | 0.136 |
| DEPTH4-(E) | 15 | 1.616 | 4 | 134 | 0.174 |
| TURBIDYA-(E) | 16 | 1.415 | 4 | 133 | 0.232 |
| POOLA -(E) | 17 | 1.064 | 4 | 132 | 0.377 |
| CR -(E) | 18 | 1.019 | 4 | 131 | 0.400 |
| RAPIDA -(E) | 19 | 1.127 | 4 | 130 | 0.347 |
| RIFFLEA -(E) | 20 | 1.010 | 4 | 129 | 0.405 |
| DEPTH1-(E) | 21 | 1.059 | 4 | 128 | 0.380 |

| Appx. R cont. | No. of vars. in | F-value | df 1 | df 2 | *p*-level |
|---|---|---|---|---|---|
| STREAM -(E) | 1 | 4.886 | 4 | 148.000 | 0.001 |
| RAPIDS -(E) | 2 | 4.109 | 8 | 294.000 | 0.000 |
| PA -(E) | 3 | 3.658 | 12 | 386.571 | 0.000 |
| DEPTH5-(E) | 4 | 3.508 | 16 | 443.620 | 0.000 |
| RUNS -(E) | 5 | 3.206 | 20 | 478.544 | 0.000 |
| VALUE -(E) | 6 | 3.019 | 24 | 500.077 | 0.000 |
| HARD_PAN-(E) | 7 | 2.908 | 28 | 513.410 | 0.000 |
| MAXAGEL-(E) | 8 | 2.825 | 32 | 521.578 | 0.000 |
| REPLENL-(E) | 9 | 2.905 | 36 | 526.382 | 0.000 |
| LAKE -(E) | 10 | 2.832 | 40 | 528.927 | 0.000 |
| PH -(E) | 11 | 2.713 | 44 | 529.908 | 0.000 |
| FI2 -(E) | 12 | 2.635 | 48 | 529.777 | 0.000 |
| SO -(E) | 13 | 2.568 | 52 | 528.837 | 0.000 |
| ALGAEA -(E) | 14 | 2.523 | 56 | 527.294 | 0.000 |
| DEPTH4-(E) | 15 | 2.471 | 60 | 525.297 | 0.000 |
| TURBIDYA-(E) | 16 | 2.411 | 64 | 522.948 | 0.000 |
| POOLA -(E) | 17 | 2.332 | 68 | 520.324 | 0.000 |
| CR -(E) | 18 | 2.258 | 72 | 517.483 | 0.000 |
| RAPIDA -(E) | 19 | 2.200 | 76 | 514.467 | 0.000 |
| RIFFLEA -(E) | 20 | 2.140 | 80 | 511.310 | 0.000 |
| DEPTH1-(E) | 21 | 2.089 | 84 | 508.037 | 0.000 |