American Fisheries Society Symposium 44:307–315, 2004

A Historical Perspective on the Philosophy behind the Use of Propagated Fish in Fisheries Management: Michigan's 130-Year Experience

GARY E. WHELAN[1]

Michigan Department of Natural Resources, Fisheries Division
Post Office Box 30446, Lansing, Michigan 48909, USA

Abstract.—Michigan's fish hatcheries were originally developed in the 1870s in response to rapidly declining commercial fish stocks caused by massive overharvest and habitat degradation. While the writings of early fish culturists decried the waste from the commercial fishery and the destruction of critical habitat, there was little political will to do anything but stock fish, so for nearly 50 years, hatcheries became the only fishery management tool to address these problems. In the 1920s and 1930s, fishery managers recognized that more than hatcheries were needed to restore fish populations. Efforts were initiated to improve habitat and strictly control harvest. Hatcheries were still the primary focus of fisheries management, but culture policy changed to the production of fingerling rather than fry. This philosophy held sway until 1950 when a combination of research on fingerling returns and social demand for instant recreation forced the start of the legal-size trout program along with a reduction in the coolwater culture program in Michigan. In 1964, a complete shift in thought occurred. The legal-size trout program was discontinued, habitat rehabilitation was emphasized, and a policy of a 1:1 return to the creel as stocked was instituted. Propagated fish also became a tool for ecosystem change and Great Lakes salmonid stocking started in earnest to balance these prey dominated systems. In the 1970s and 1980s, coolwater fisheries programs were re-examined as water quality improvements from the Clean Water Act opened up new habitat for the re-establishment of these species. Large-scale culture operations for fingerling walleye, northern pike, muskellunge, and lake sturgeon culture operations were reinitiated. In the 1980s and 1990s, public concern over hatchery programs forced managers to review fish culture and stocking practices, and hatcheries became one of many biological, legal, and sociological tools to rehabilitate fish populations. Current Fisheries management philosophy in Michigan uses cultured fish to meet four objectives: (1) re-establish extirpated species, (2) rehabilitate degraded fish populations, (3) provide for ecosystem balance, and (4) create new sportfishing opportunities.

Introduction

The use of propagated fish has been, and remains, one of the key tools of fisheries management in the state of Michigan since 1873, the year that the Michigan Fisheries Commission was formed. Technology, fish culture methods, and the uses of propagated fish have all evolved over the last 130 years. To understand the changes that occurred, it is critical to understand the environmental and social context in which propagated fishes were used. The objectives of this paper are to trace the history of the philosophy behind the use of propagated fish in Michigan, to describe the reasons why changes occurred, and to discuss the current philosophy that guides the state of Michigan's fish production system.

[1] E-mail: whelang@michigan.gov

The Fry and Johnny Fish-Seed Era (1873–1929)

The initial uses of propagated fish were to replace native fish communities eliminated by human development, the desire of immigrants to bring familiar and important food items with them, the need to feed an increasing number of new residents, and the need to provide for a new and growing sportfishing industry. By the 1870s, native fish communities in much of Michigan were either in decline or had been elimi-

nated by a combination of landscape scale habitat destruction, water pollution, dam construction, and overharvest.

Early fisheries workers understood the problems they were facing but were unable to implement any type of harvest regulations or to prevent the landscape scale destruction of fishery resources because the political and social will to do so simply did not exist at that time (Bogue 2000). A demonstration of this can be found in the earliest Michigan Fish Commission (1873) document where George Jerome, Michigan's first fisheries superintendent wrote that he had been asked three questions by legislators and that he answered affirmatively to all three. The questions were (1) Can waters abounding with fish be depleted by excessive fishing; (2) If so, can they be restored by reasonable effort; and (3) Is fish culture the answer? In other parts of the First and Second Biennial Reports of the Michigan Fish Commission (Michigan Fish Commission 1873, 1875), Jerome decried the waste of fish by commercial fishing interests and the massive pollution caused by the industrialization of Michigan. Subsequent writings by Milner (1882) documented the large-scale waste in the Great Lakes commercial fisheries.

Great Lakes tributary streams were altered during this 67-year period. Nearly the entire state of Michigan was deforested during the period of 1860–1900 and as much land as possible drained and converted to farmland. River systems were the major transport systems used to move logs to sawmills. Log drives, the mass movements of cut logs, were conducted on nearly every stream and river in the state, loading massive amounts of soil into streams and requiring large scale de-snagging operations to remove existing large woody debris that were barriers to log movement from their channels. The landscape scale deforestation efforts required many small and large splash dams to move logs, creating extreme flood events, subsequent drought flows, and fragmented watersheds. Lumber mill operations required additional dams to produce mechanical energy to run saws and these further fragmented rivers, usually near the river mouth. A combination of poor forestry practices, plus industrial and lumbering dams, degraded or isolated many miles of stream habitat (Gates et al. 1983) and directly contributed to the extinction of the Michigan grayling *Thymallus arcticus*, along with declines of many other native species (Westerman 1974).

Industrial development of Michigan contaminated many watersheds with untreated wastes that prevented the free movement of fish and greatly reduced available habitat (Gates et al. 1983). Pollution impacts were found throughout Michigan, eliminating fish communities entirely, or degrading large reaches of river systems and many lakes to the point where intolerant native fish communities were displaced by pollution tolerant species such as common carp *Cyprinus carpio*.

The final key factor, overharvest, further reduced or eliminated native fish communities. Both commercial fishing and the growing sportfishery were essentially unregulated until the 1920s when initial science-driven harvest regulations and laws backed up by a rapidly growing number of professional conservation law officers were put into place. These laws included the establishment of the Department of Conservation with broad public trust authorities and enforcement powers. Regulations placed into effect included a broad array of closed seasons, size limits, and possession limits.

Fisheries workers responded to these needs and declining fish populations simply by culturing and stocking large numbers of fry. The technology and cultural methods to hold large numbers of large-sized fish had not yet been developed, although small numbers of large fish were cultured and broodstocks were maintained (Bowen 1970; Westers and Stauffer 1974). A relatively small infrastructure was needed to support fry culture, and in 1900, the state of Michigan maintained six hatcheries in Detroit (lake whitefish *Coregonus clupeaformis* and walleye *Sander vitreus*), Drayton Plains (largemouth bass *Micropterus salmoides* and smallmouth bass *M. dolomieu*), Mill Creek – Grand Rapids (largemouth bass, smallmouth bass, and walleye), Paris (brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, and rainbow trout *Oncorhynchus mykiss*), Harrietta (brook, rainbow, and brown trout) and Sault Ste. Marie (lake whitefish) (Westers and Stauffer 1974). The key technological problems for rearing larger-sized fish included the lack of a fundamental understanding of fish physiology and fish nutrition, a lack of information on the fish life histories, inadequate water supplies, and inappropriate water quality (Bowen 1970).

During the period from 1874 to 1884, nearly 152 million fry representing 15 species were stocked by the Michigan Fish Commission. The majority of these fish (93.7%) were lake whitefish, with production of this species peaking in 1929 when 83 million were planted (Westers and Stauffer 1974). Lake whitefish was the most important commercial species of the time and massive stockings were done in the Great Lakes to rehabilitate depressed populations and in inland waters to create new food fisheries.

Large numbers of exotic species were planted in Michigan from 1873 to 1921, including Atlantic salmon *Salmo salar* and Chinook salmon O. *tshawytscha*, brook trout (only native to the Upper Peninsula and a few Lower Peninsula streams), brown trout, rainbow trout, common carp, walleye (planted into waterbodies where absent), largemouth and smallmouth bass (planted into waterbodies that lacked them), and rainbow smelt *Osmerus mordax*. Fry planting for nearly all of these species were reported to have some level of success as numerous angler reports of catching stocked fish were detailed in Michigan Fish Commission documents from the period. Most of these species had high food or recreational value for longtime or newly arrived Michigan residents. Philosophical insights about the development of United States waters for food can be found in the writings of Spencer Baird (Stickney 1996), where he stated:

> This has rightly been considered an object of the greatest importance in view of the rapidly-increasing population of the United States and the almost corresponding diminution in the average yield of vegetable food by the farming-lands, and it not considered exaggeration to say that the water can be made to yield a larger percentage of nutriment, acre for acre than the land.

Nonindigenous fish species were introduced widely during this period without any concern about effects on existing fish populations.

Along with stockings came the direct transfer of juvenile fish between waters and states. Examples include the capture of 1,705,800 American eels *Anguilla rostrata* at Troy, New York from 1878 to 1884 and their transplantation to many Michigan waters. Native transplants using smallmouth bass and yellow perch *Perca flavescens* and other species were routinely conducted. Many of these fish were collected in the Great Lakes and transported to inland water in Michigan.

Stocking policies changed in 1921 with the creation of the Michigan Department of Conservation – Fish Division, which assumed the duties of the Michigan Fish Commission. Planting of exotic species, such as American eels, Chinook salmon, and Atlantic salmon, was terminated and the focus turned to the stocking native species, such as brook trout, lake trout, and walleye, or naturalized species, such as brown trout. Michigan Department of Conservation fish culturists and biologists had recognized that many fry plants were unsuccessful (Michigan Department of Conservation 1928) and, by the mid 1920s, initiated a movement toward planting fingerlings. The likely reason for the failure of many fry plantings, particularly for lake whitefish and lake herring *C. artedi*, was the fact that stocking densities were too low (Todd 1986). By 1929, Michigan's fingerling program was no longer an experiment; fingerling stocking became the official policy of the state (Michigan Department of Conservation 1930).

The success of early fish culturists during the 1873–1929 period should not be underestimated. By the early 1880 s, they understood the conditions where and when plants would or not succeed (Michigan Fish Commission 1883). The Michigan Fish Commission routinely received anecdotal reports from constituents indicating that some fry stockings were successful (Michigan Fish Commission 1879), and many species were successfully introduced to new waters. An example of the early culturists' success is the regionally important walleye fishery in Lake Gogebic that was a famous smallmouth bass fishery before walleye were stocked. Walleye fry were first stocked in 1904, likely from Saginaw Bay reef spawning stocks, and within 20 years, walleye dominated the fishery. On the other hand, as Todd (1986) showed, some large-scale fry planting operations were far less successful.

The Sportfish for All Era (1930–1949)

By the 1920s, most of Michigan's aquatic habitats remained degraded from earlier landscape level land use changes. Rapid industrialization of the state increased greatly the effects from untreated industrial and municipal wastes. The 1930–1949 period was the peak of hydroelectric dam development in Michigan. Dams were constructed on nearly every high gradient river reach in the state, greatly increasing the fragmentation of Michigan's river systems. Harvest pressures on inland fish populations increased steadily as interest in sportfishing grew rapidly during the 1930s and 1940s due to increases in leisure time, resulting from changes in labor laws and increases in disposable income. While harvest restrictions were implemented, regulation compliance was low. Law enforcement efforts were ineffective because of the lack of roads, effective communications, and sufficient manpower. The above conditions led to low spawning populations and caused recruitment problems in many waters.

In response to changes in angler preference for sportfish species and concerns about fry survival, the fish culture efforts in Michigan shifted to stocking

strictly fingerling-sized native or naturalized species with sporting qualities. Methods to improve returns of fingerling sportfish were developed and documented in research by Eschmeyer (1937) and Leonard (1938) who determined that the removal of competing species by using toxicants in lakes would greatly increase survival and angler harvest of stocked salmonids, brook trout, and rainbow trout. This research did not acknowledge the ecological costs to native fish communities caused by these management actions or the continuing costs to maintain monocultures using toxicants. Monocultures of stocked trout were maintained widely to enhance the performance and returns of hatchery-propagated fish at this time and remained in widespread use into the late 1980s in Michigan.

The emphasis on sportfish species was reinforced by Michigan Department of Conservation policy decisions that reduced commercial fish management efforts on the Michigan's Great Lakes waters. Stocking of commercial fish species for the Great Lakes were greatly diminished. Cultured species shifted from Great Lakes commercial species, such as lake whitefish, to inland sport species, including stream salmonids (brook, rainbow, and brown trout) and inland coolwater fish (bluegills *Lepomis macrochirus* and largemouth bass).

The policy decision to shift to fingerling sportfish production required a large increase in infrastructure to support needed production. In the 1930s, the state of Michigan operated 15 fish hatcheries, 13 trout rearing stations for the increased space requirements of fingerling trout rearing, and 24 bass and bluegill rearing ponds (Westers and Stauffer 1974). This decision also greatly increased production costs, mainly for fish food and staff, which by 1940 rose to $70,000 annually for fish food alone (Westers and Stauffer 1974).

In the early 1930s, the predominant species produced in Michigan's hatcheries was brook trout with approximately 5 million fingerlings of this species were stocked annually (Westers and Stauffer 1974). By the late 1930s, fish culturists and biologists thought that larger fish would survive better (Michigan Department of Conservation 1938), in spite of concerns raised by Hazzard and Shetter (1938) on the effects of propagated fish on wild trout populations. Increasing numbers of yearling trout were produced with 250,000 yearling brook trout produced by the mid 1940s. Total numbers of brown and rainbow fingerlings produced annually reached 2–4 million fish by the end of the 1940s. Fry, yearlings, and legal-sized lake trout *Salvelinus namaycush* were also produced for inland waters with a focus on fry and fingerlings in the 1930s when approximately 300,000 were stocked annually. As the size of the propagated lake trout increased, the numbers stocked declined to an annual range between 25,000 and 100,000 fish in the 1940s.

Production of warm and coolwater species also increased greatly during this period and focused on bluegills, largemouth bass, smallmouth bass, and walleye. Bluegill production peaked at 23 million fingerlings in 1939. The production of bass fingerlings reached an annual production of 1 million per year during this period. Walleye culture focused on fry production because culture techniques were unavailable to rear larger sizes. Production peaked at 100 million fry in 1947.

Fish managers often used large-scale transfer of fish to increase fish populations, typically from Great Lakes tributaries to inland waters. Yellow perch was the most common species "rescued" from their spawning runs in Great Lakes tributary streams and transfers of this species to inland waters reached 11 million in 1941 (Michigan Department of Conservation 1942). During spawning runs in Great Lakes tributary streams, low numbers of adult steelhead trout (adfluvial rainbow trout) were annually transferred above barrier dams to provide sportfishing opportunities for "trophy" fish in Michigan inland trout streams.

The cultural methods during this period also affected the performance of hatchery fish. The lack of knowledge about fish health and good hatchery biosecurity practices caused epizootic disease outbreaks of bacterial gill disease, furunculosis, fungus infections, and *Gyrodactylus* sp. infestations, with large losses noted at many hatcheries (Krull 1930, 1931; Allison 1943). It is likely that many diseased fish were stocked in Michigan waters and that disease agents were introduced into populations where they had not been endemic.

Knowledge of fish genetics was so limited that genetic principles were essentially ignored in broodstock management during this period. Fish were produced using small numbers of broodstock fish, resulting in a small effective population size for most species, except for walleyes and steelhead, which depended on egg takes from wild spawning runs. Breeding strategies for both wild and captive fish stocks almost always used batch fertilization of gametes from just a few individual males and females. It is likely that inbreeding depression, and possibly outbreeding depression, caused long-term problems in the fitness of these fish, although these consequences have not been

documented. The lack of knowledge about genetic diversity during this and previous time periods may continue to affect fish populations to this day. Self-sustaining fish populations that resulted from stockings during this period are likely to have had low effective population sizes and a high degree of relatedness from founder effects.

While the key fish management tool of this period was the stocking of hatchery fish, the initial efforts in habitat improvement/rehabilitation were begun. Research by Hubbs et al. (1933), Tarzwell (1935, 1936), and Eschmeyer (1936) documented the importance of habitat for fish production, acknowledged the historical impacts on Michigan's watersheds, and developed methods to improve/rehabilitate stream and lake habitat. These newly developed habitat rehabilitation methods, targeted at sportfish, were implemented by large-scale habitat projects backed by low-cost federally funded labor programs such as the Civilian Conservation Corps.

The clear emphasis of this period was to produce inland sportfisheries for the growing angling community, particularly for trout. All policies were directed to toward maximum sustainable yield of sportfish without any regard for other species.

The Instant Fishery Era (1950–1964)

By the 1950s and 1960s, evidence was increasing that survival of fingerling-sized fish was insufficient to meet angler demands. Research using marked fish indicated that less than 2% of the fingerlings were being returned to the creel (Shetter 1939). Hazzard and Shetter (1938) and Shetter and Hazzard (1940) demonstrated that stocking legal-sized fish in streams provided large increases in the returns to the creel. Similar research in lakes with other piscivores documented similar improvement (Eschmeyer 1937). This research was the basis of Michigan's fish stocking policy of the time that used legal-sized fish in streams during the early spring and open season, fall fingerlings in small lakes, and legal-sized fish in large lakes (Westers and Stauffer 1974).

Environmental conditions in the Great Lakes region were at their lowest point with widespread pollution problems, rapid urbanization, and the complete domination of Michigan's Great Lakes fish community in lakes Michigan and Huron by exotic alewives *Alosa pseudoharengus* after the native piscivores had been eliminated (Whelan and Johnson 2004, this volume). An indication of the poor environmental conditions and related management strategies during this period was that the state of Michigan did not require a fish license to fish in the Great Lakes, and no active fisheries management other than to initiate Lake Superior lake trout rehabilitation efforts using propagated lake trout were conducted.

The desire by stakeholders and constituents for instant technologically made fisheries, along with the need to mitigate loss of habitat from large-scale development projects, led to a rapid increase in number and size of fish hatcheries. While habitat improvement projects continued in Michigan trout streams at this time, their aim was to improve fishing opportunities for specific species, without considering how to improve watershed conditions for the entire fish community. The hatchery goal at this time was to produce maximum numbers of legal-sized trout. This came at a considerable cost. These high costs forced the state of Michigan to re-examine the fish production infrastructure, and a number of smaller hatcheries were closed in the early 1960s.

Warmwater and coolwater fish culture were greatly reduced during this period to divert resources to producing maximum numbers of catchable-sized brook, brown, and rainbow trout. Another factor leading to the reduction in coolwater rearing was poor success in rearing fingerling-sized walleye. While most of the warm- and coolwater production efforts on bluegills, largemouth and smallmouth bass, and walleyes were eliminated in Michigan, small-scale fish culture efforts were initiated on other large predators such as northern pike *Esox lucius* and muskellunge *E. masquinongy*, at the request of anglers.

Stocking policy focused entirely on providing instant put-and-take trout fisheries. Little consideration was given to the effects of these policies on other species or on self-sustaining trout populations, even though Shetter and Hazzard (1940) expressed concern about the effects of legal-sized fish on wild brook and brown trout populations. The use of propagated fish as ecosystem-level tools for energy management was not yet considered. The focus on legal-sized fish caused a growing disenchantment with fishing aesthetics as high densities of anglers quickly harvested legal-sized fish. Concerns were also voiced about the perceived lack of sporting qualities of the hatchery fish. The formation of concerned angler groups such as Trout Unlimited in Michigan in 1959 was one result of the state's stocking policy. Finally, the costs of this policy were high to the Michigan Department of Conservation's budget. Data from Fukano (1963) documented cost of legal-sized fish to the creel as $1.00 each in 1963 U.S. dollars, which was not considered

to be sustainable at that time (Michigan Department of Conservation 1964).

The cultural methods during this period continued to compromise the performance of hatchery-propagated fish. While knowledge about fish health and good hatchery biosecurity practices had improved greatly, large epizootic disease outbreaks, such as bacterial gill disease, furunculosis, fungus infections, and bacterial kidney disease, still occurred at many hatcheries. Many diseased fish were stocked in Michigan waters because the political costs from destruction of diseased fish were high and a primary goal was to have fish survive long enough to be harvested. The long-term survival of these fish was not important to many fish managers of this period. Disease agents were still transmitted rapidly to wild stocks where the disease was not endemic during this period. New parasites and pathogens likely were introduced by the mass transfers and trading of fish from other parts of the United States to Michigan and from Michigan to other part of the United States.

While the knowledge of fish genetics improved during this period, genetic principles continued to be ignored in broodstock management during this period. Fish were still produced using small numbers of broodstock fish and resulting in a small effective population size for most species, except for steelhead that depended on egg takes from wild spawning runs. Breeding strategies for both wild and captive fish stocks still used batch fertilization of gametes from just a few individual males and females at a time. The lack of sound genetic and breeding practices during this and previous time periods probably continues to affect fish populations to this day.

The Holistic Era (1964 to Present)

In 1964, the Department of Conservation reviewed and changed the policies concerning fisheries management along with those for propagated fish (Michigan Department of Conservation 1964). A growing human population, coupled with declining environmental conditions in Michigan's waters, required an overhaul of fisheries policy and management strategies. It was impossible to meet the expanding recreational needs and public trust requirements with the existing policies. Changes implemented included a large increase in evaluation and inventory work, an increase in land acquisition for fishing access and habitat protection, a new emphasis on the Great Lakes, a revised regulation structure, a reduction in stream improvement projects for single species purposes, and the construction of state fishing impoundments to increase angling opportunities.

The key propagated fish program change was to terminate the legal-sized brook, rainbow, and brown trout program because of the high cost and perceived low return of this program. The new policy required all fish stockings to return as many kilograms to the creel as had been planted, an objective that legal-size trout planting programs were not able to attain. The new policy acknowledged a role for using propagated fish to rehabilitate depressed fish populations and as ecosystem tools. Trout planting sizes focused on sublegal-sized yearling trout to ensure that fish were not removed immediately by the large numbers of hatchery truck followers and to allow some natural selection to occur on the stocked fish where they were stocked with the intent of establishing self-sustaining populations.

A new emphasis was placed on expanding and improving Michigan's Great Lakes fisheries. This was made possible by the implementation of effective sea lamprey control efforts and new efforts to improve water quality. The new focus was spurred by the demand for new sportfishing opportunities and the need to change the energy concentrated in alewives into desirable piscivores such as coho salmon *O. kisutch* and Chinook salmon (Tody and Tanner 1966). To change the energy base in lakes Michigan and Huron, large inputs of propagated salmonids would be required to prey on the dominant alewife population. To supply the required fish, major changes in the fish production system would be required, including the implementation of high-density rearing, improved fish feeds, improved fish health practices, and consolidating widely dispersed hatchery system into six large facilities.

Supporting the more holistic view of fisheries was a philosophical change in the Michigan Department of Conservation from an agency that only managed public lands and fish and wildlife resources to one that continued to have the public trust responsibilities along with new regulatory charges to clean up the state's air, land, and water. These changes resulted from the implementation of environmental regulations in the late 1960s and early 1970s, and a new awareness of the value of public trust resources, including clean water and air, by the citizens of the state. The department's name was changed from the Michigan Department of Conservation to the present Michigan Department of Natural Resources in 1968 in recognition of the broadened responsibilities of the department. In 1995, the environmental regulatory

functions were moved to the new Department of Environmental Quality. The environmental laws implemented in the 1970s completely altered the resource landscape, opening entire watersheds for fish community rehabilitation efforts. Propagated fish would be required to re-establish fish communities in these "newly" available habitats.

New regulations and regulatory structures based upon detailed fisheries data from increased inventory and waterbody sampling by the Michigan Department of Natural Resources were implemented in the early 1970s. Use of detailed fisheries data, coupled with population dynamics models to forecast the results of regulations and stocking activities, resulted in improved size structure of fish populations in Michigan waters, while ensuring that the prey bases in Lake Michigan and Lake Huron were not eliminated by aggressive fish stocking practices. The communication of these data to the public in understandable ways also improved angler's compliance with harvest regulations. Improved science-based regulations that are understood by the angler, combined with effective law enforcement using modern communication and transportation systems, have made significant contributions in protecting fish populations from overharvest, allowing propagated fish to meet their objectives.

In the late 1970s, the Michigan Department of Natural Resources reinitiated coolwater culture operations, mainly for walleye. The program was restarted because of the high angler demand for coolwater species, particularly walleye, and new habitat opportunities on a watershed to landscape scale, resulting from water quality improvements produced, in turn, by the new environmental regulations and laws. It was also viewed to a way to build on the success of the large-scale biomanipulation of lakes Michigan and Huron in areas not utilized by trout and salmon. Improvements in the coolwater culture techniques, particularly in walleye rearing methods, set the stage to rapidly expand coolwater production. The objective of the coolwater culture program remains to produce additional predators to maintain balance in Great Lakes predator–prey populations in areas where trout and salmon are unable to do so, along with providing new angler opportunities, particularly for walleyes, in inland waters.

In the mid 1980s, improved coolwater culture techniques became available for relatively rare species such as muskellunge and lake sturgeon *Acipenser fulvescens*. The ability to reliably produce these fish in larger numbers has provided new impetus to rehabilitate other depressed native and rare Michigan fish species and to re-establish these species in extirpated waters. Many of these "new" waters, now available as potential habitat, were formerly degraded in water quality and, in many cases, had no fish communities.

Finally, in the late 1980s and 1990s, ecosystem management approaches were embraced by many fisheries management agencies, including the Michigan Department of Natural Resources. This management paradigm assumes that the scale of management has expanded greatly, from individual river reaches or lakes and individual species to the consideration of all factors affecting entire watersheds or Great Lake basins and includes all of the species that reside or depend on the aquatic community. The change in scale also reawakened the need to conduct large-scale habitat improvements such as changing regulated river flow hydrographs during Federal Energy Regulatory Commission licensing proceeding and basin-level forest management during U.S. Forest Service planning processes. The roles for propagated fish in such plans must expand to meet the need for a wider range of species and strains.

Parallel to this change in the scale of management, was the rediscovery of the public trust doctrine, an English common law principle that is the basis of the citizen's ownership of fish and wildlife resources in North America. In the 1990s, constituents began to use this tool to protect fish and wildlife resources and as a mechanism to compel fisheries management agencies to consider all aquatic resources in their management mandates. An outgrowth of the requirement to consider all aquatic resources is a broadened role for propagated fish beyond simply producing sportfish for anglers.

Since 1964, the policies and uses of propagated fish in Michigan have changed substantially because of landscape scale habitat improvements, management philosophy shifts, citizen and angler attitude changes, improved regulations and enforcement of regulations, and improvements in fish culture techniques. The current policy is to use propagated fish in Michigan to achieve the following four objectives, in order of priority: (1) reintroduce extirpated fish species or populations, (2) rehabilitate degraded fish populations, (3) provide for ecosystem balance, and (4) provide for diverse sportfishing opportunities. This broadened mission for Michigan's fish production system recognizes our dual role as the manager of the public trust resource for the state's citizens along with the need to meet the requirements of Michigan's anglers for quality fishing opportunities.

To implement this policy, additional fish culture

policy changes were required and these continue today. The quality of the fish produced has become more important than the quantity of fish produced. The Michigan Department of Natural Resources has been very successful in high density rearing of salmonids, but this, at times, has come at a cost in fish quality, for example, poor fin condition that, in turn, impairs survival. For fish to meet the objectives of the agency, it is critical that they survive, and to do so, they must be of high quality. Michigan now rears lower densities of fish to improve individual fish quality. The effect of these fish on fishing and the environment is as high as or higher than when maximum densities were reared. Improvements have been made and must continue in fish transportation and stocking practices, including the incorporation of new water quality sensors on fish tanks and the use of acceptable temporal stocking windows to maximize survival. The incorporation of genetic principles to conserve genetic diversity, which includes the determination of compatible genetic stocks, the direct control of broodstocks, and the use of appropriate breeding strategies, such as 1:1 spawning of males and females and the use of all segments of spawning runs, are critically important in producing high quality fish to meet the current objectives for Michigan's propagated fish. Fish health capabilities have been and must continue to improve to prevent epizootics from occurring both in the wild and in hatcheries to include better pathogen detection methods, improved vaccines, and better hatchery pathogen control practices. Epizootics such as the bacterial kidney disease outbreak of the late 1980s in the Great Lakes can result in large scale ecosystem level changes by decreasing piscivore abundance, which, by the early 1990s, caused an increase in nonnative alewife numbers, as well as substantial reductions in the fishery.

Conclusion

Fisheries management agencies will need to use propagated fish as a fundamental fisheries management tool for the foreseeable future. It is unlikely that the increasing demands of anglers and the continuing habitat degradation from development pressures will allow for the development of strictly self-sustaining fish populations with no need for propagated fish. The Michigan Department of Natural Resources estimates that currently 40% of the economic value of Michigan's fisheries and 70% of the economic value derived from Great Lakes fisheries in Michigan stem from and are reliant on propagated fish (Michigan Department of Natural Resources, unpublished data). Propagated fish are required to maintain the value of Michigan's fisheries and will continue to be so in the future.

Increasingly, North American fisheries managers understand their public trust responsibilities and the requirements for these agencies to protect and manage all of the state's aquatic resources. Because the public now has far more information about aquatic resources available to them and is interested in more than consumptive uses of aquatic resources, North American fisheries management agencies can no longer only stock fish strictly to benefit anglers. Fisheries managers cannot ignore the other public trust resources that we are legally mandated to protect and manage. Successful management of our resources on an ecosystem level, including all members of the aquatic community, requires a holistic, yet pragmatic, perspective and a much broader role for propagated fishes than the harvest focused fisheries management of the past.

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