# Salmonine Community

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Populations of top predators in the open-water Lake Michigan fish community changed dramatically within the past 100 years (Smith 1968; Wells and McLain 1972). Prior to the 1900s, the community was dominated by a single salmonine, the lake trout, and a member of the cod family, the burbot. Lake trout populations were extirpated, and burbot populations were greatly reduced by the 1950s as a result of overexploitation by the commercial fishery and high rates of predation by sea lamprey. The current predator population is composed of mainly introduced salmonines, including seven species of exotic trout and salmon, and lake trout. Among the introduced salmonines, chinook salmon, rainbow trout, coho salmon, and brown trout are prominent and are considered to be the key species (Fig. 10; Wells and McLain 1972).

Pink salmon, an accidental introduction into Lake Superior in the 1950s, naturalized and spread to other Great Lakes, including Lake Michigan where populations are small. Brook trout and the brook trout-lake trout hybrid (splake) are stocked in small numbers at a few inshore locations in the northern part of the lake and Green Bay.

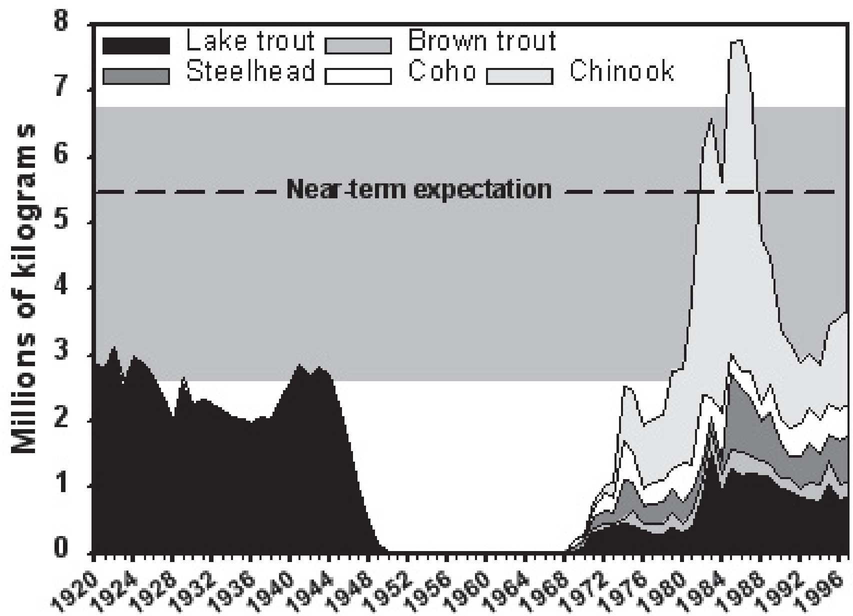


Fig. 10. Harvest of major salmonines from Lake Michigan 1920-1997, target harvest range (shaded area), and near-term yield expectations (dashed line) (Eshenroder et al. 1995).

Salmonines were introduced into the Great Lakes for several reasons. Rainbow trout, brook trout, splake, and brown trout were introduced to provide more-diverse fishing opportunities, whereas chinook and coho salmon were introduced to control the large populations of introduced alewife and diversify fishing opportunities (Tody and Tanner 1966; Keller et al. 1990).

Lake Michigan's salmonine fisheries are currently sustained in large part by stocking. However, as introduced salmonines naturalized, determining the amount of natural reproduction is increasingly important. Because lake trout is the only major salmonine predator that was native to Lake Michigan and knowledge of impediments to their recruitment is incomplete, rehabilitation remains an important and yet unattained goal for managers and researchers.

## Salmonine Objectives and Yields

The FCOs for Lake Michigan salmonines (trout and salmon) are: 1) to establish a diverse salmonine community capable of sustaining an annual harvest of 2.7-6.8 million kg, of which 20-25% is lake trout, and 2) to establish self-sustaining lake trout populations (Eshenroder et al. 1995). These objectives recognize the limits of the system and the need to balance a desire for abundant populations of top predators with the possibility that overstocking could lead to a collapse of planktivore populations and instability of predator populations. The decline in chinook salmon fisheries during the late 1980s provided an example of the limits of the Lake Michigan fish community. The objectives of the current management approach include sustaining a diverse predator community that supports sport and commercial fisheries, and that utilizes alewife and rainbow smelt populations sufficiently to minimize the negative influences of these exotic planktivores on native species, especially on the bloater (Eshenroder et al. 1995). Declines in alewife abundance and increases in bloater abundance during the early 1980s emphasized the advantages of a diverse salmonine community that could take advantage of a changing prey-fish community. The lower bound of the desired salmonine yield, 2.7 million kg, was determined from the historical catch of lake trout before the collapse of the native population. The upper bound, 6.8 million kg, was determined from biomass size-spectrum models (Borgmann 1987; Sprules et al. 1991) assuming 100% ecological efficiency. Model estimates indicated that a mix of salmonine species would more efficiently use the pelagic fish community, and thus could support higher yields than were realized from a fish community with only lake trout as the top predator. The LMC agreed to the following species-specific near-term yield expectations (within the 2.7 to 6.8 million-kg range) chinook salmon—3.1 million kg; lake trout—1.1 million kg; coho salmon—0.7 million kg; rainbow trout—0.3 million kg; and brown trout—0.2 million kg; or an overall lakewide yield of 5.5 million kg (Eshenroder et al. 1995; Fig. 11). The LMC recommended that these initial expectations be refined by evaluating the relation between yield (sport, commercial, harvest-weir) and the mix of predators in the system and that a determination be made as to how these different mixtures of species meet a variety of needs identified by society.

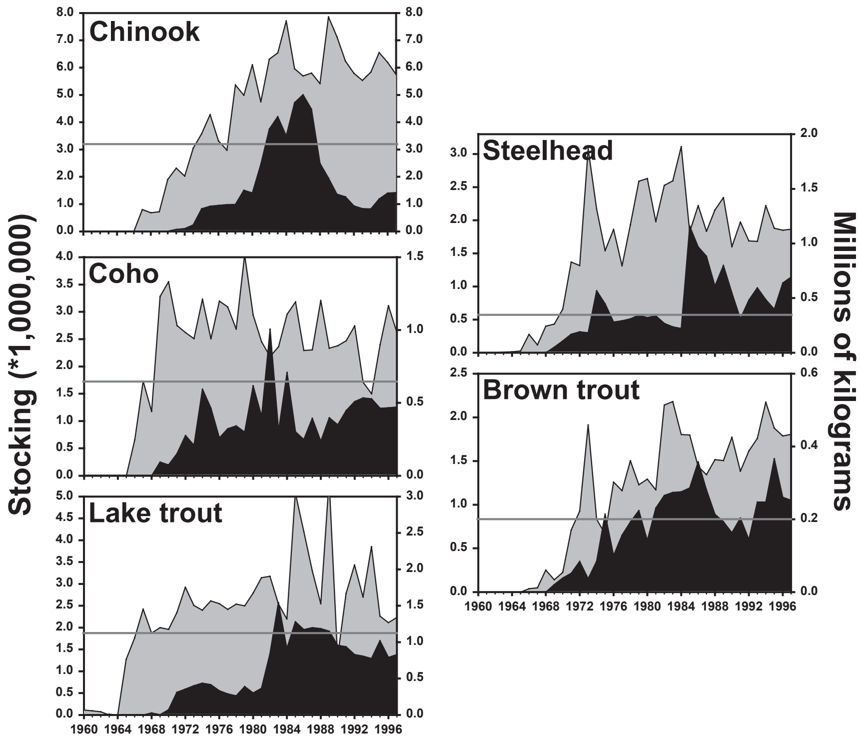


Fig. 11. Estimated yield (kg, dark shaded area) of chinook salmon, rainbow trout, coho salmon, brown trout, and lake trout; number stocked (light shaded area); and near-term yield expectations (line) identified in Eshenroder et al. (1995).

During the 1980s and 1990s, overall yield was within the expected yield range identified in the FCOs, although in recent years it has been substantially below the near-term yield expectation of 5.5 million kg (Fig. 10). Yields exceeded 5.5 million kg during the mid-1980s, but declines in chinook salmon biomass (Fig. 12) and fishing effort (Benjamin and Bence 2003) led to substantial reductions in yield. Although estimated predator biomass increased recently, fishing effort remains much lower than in the mid-1980s (Bence and Smith 1999; Benjamin and Bence 2003).

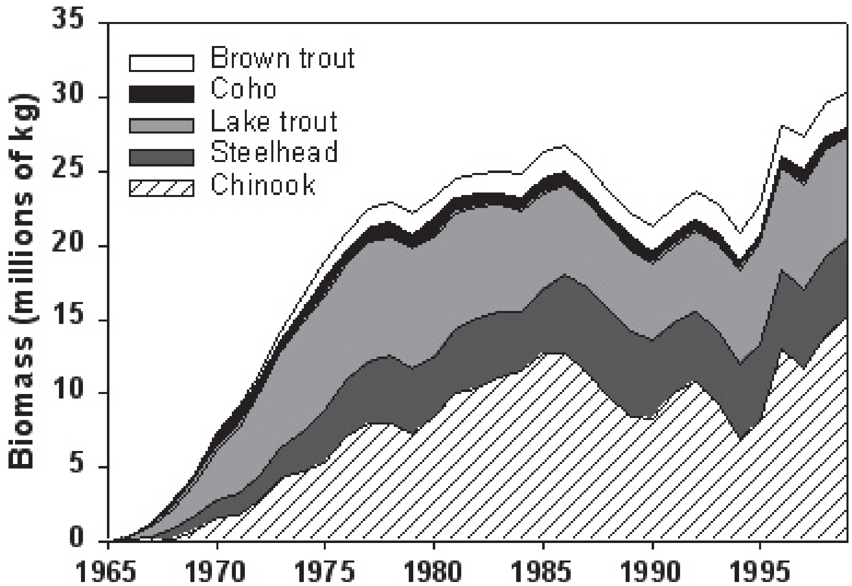


Fig. 12. Estimated biomass of salmonines in Lake Michigan, 1965-1999 (Connect Model; Rutherford 1997).

## Chinook Salmon

The annual yield of chinook salmon was less than half of the 3.1 million-kg near-term yield expectation during 1980-1999 except in 1984-1989 (Fig. 11). During the late 1980s and early 1990s, population-model estimates of chinook salmon biomass (based on recreational catch statistics) declined significantly (Rutherford 1997; Fig. 12), probably as a result of density- and forage-mediated increases in disease (Holey et al. 1998). Estimates of biomass for the mid-1990s to late 1990s were at or above former levels. Yield has not increased proportionately with increases in biomass, in part because fishing effort has not increased to levels seen during the 1980s. Management agencies reduced stocking levels of chinook salmon in recent years in an attempt to improve survival by reducing population density.

The relation between the number of chinook salmon stocked and the number harvested changed following the population collapse in the late 1980s. Sport harvest of chinook salmon was positively related to numbers stocked through the late 1980s, but the relation was no longer apparent after 1990 (Fig. 11; Hansen et al. 1990; Hansen et al. 1991; Hansen and Holey 2001). Hence, it now appears that managers cannot increase the yield of chinook salmon simply by increasing the number stocked. Even though the predicted biomass has rebounded to pre-population crash levels or greater, yield remains below the 3.1 million-kg near-term expectation level (Fig. 13) due to reduced fishing effort. Whether or not the chinook salmon harvest can recover to the high levels achieved in the 1980s is now in question. Managers should reexamine the yield expectation for this species.

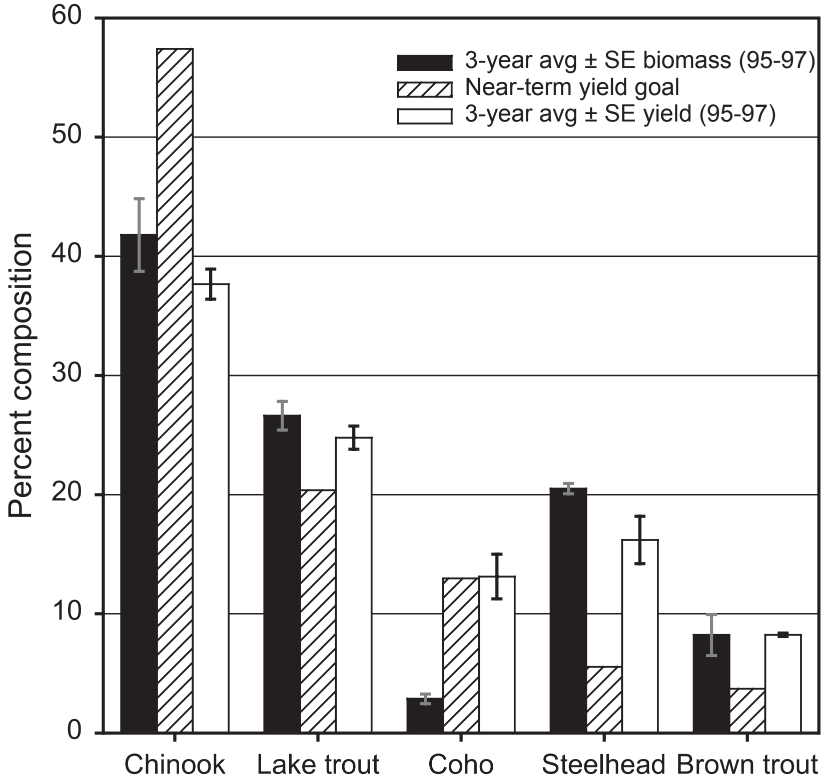


Fig. 13. Species composition of near-term yield targets from the fish-community goals (Eshenroder et al. 1995) compared to 1995-1997 mean actual yield (white bars) and 1995-1997 mean modeled estimate of relative biomass (solid bars).

**Coho Salmon**

The annual yield of coho salmon increased with increased stocking in the early years of the program, but numbers stocked have not been reflected in recent yield estimates (Fig. 11). Coho salmon were consistently harvested at levels well below the near-term expectation established in the FCOs (Fig. 11). However, the percentage contribution to the harvest was close to the expectation (Fig. 13). Coho salmon make up the lowest portion (3%) of the overall biomass of the five key species in Lake Michigan, but they are expected to produce 13% of the harvest. Coho salmon are short-lived, very fast growing, and recruit quickly to the fishery. Consequently, their biomass estimates at the beginning of the year are often well below their annual harvest. Given the yield history and current stocking rates, the near-term yield expectation for coho salmon is probably not realistic.

### Rainbow Trout and Brown Trout

Yield of rainbow and brown trout increased during the late 1960s and 1970s as stocking increased (Fig. 11). The relation between yields and stocking in recent years warrants further analysis. Yields and percentage contribution to total salmonine yield for these two species have remained consistently at or above expectations (Figs. 11, 13), so current near-term expectations are probably realistic.

### Lake Trout

Yield of lake trout in most years since rehabilitation efforts began in the 1960s has been below the near-term yield expectation identified in the FCOs (Fig. 11). However, that part of the FCOs that state that lake trout should constitute 20-25% of the total harvest has consistently been met in recent years (Fig. 13).

## Natural Reproduction and Self-Sustaining Populations

Naturalized populations of salmonines are believed to play an increasingly important role in Lake Michigan fisheries. The FCOs emphasize the desirability of enhanced natural reproduction and establishment, to the extent possible, of self-sustaining populations. Naturalized populations require less-intensive management, may result in more-stable ecosystem dynamics, may increase fitness of populations through genetic selection, and in general are expected to have better survival and productivity in the wild than hatchery-reared fish (Chilcote et al. 1986; Leider et al. 1990; Berejikian et al. 1996). Regulation of hydropower facilities, habitat improvement, and improvements in the water quality of riverine and Great Lakes environments likely contributed to increased productivity of naturalized fish (Holey 2005). In particular, naturalized chinook salmon now make up a large portion of the chinook salmon population. Based on identification of oxytetracycline (OTC) marks in 1992 and 1993, about 30% of the sport harvest of chinook salmon was made up of naturalized fish (Hesse 1994). Naturalized rainbow trout also make up a large portion of the rainbow trout sport harvest. The proportion of naturalized fish in the entire harvest has yet to be determined, but data from several highly suitable tributaries in Michigan indicate that the contribution of naturalized fish to spawning runs may be as high as 100% (Seelbach and Whelan 1988; Seelbach 1989; Seelbach 1993; Seelbach et al. 1994). In tributaries that are less suitable for rainbow trout reproduction (e.g., St. Joseph and Grand Rivers in Michigan), wild rainbow trout comprise 5-20% of the run (Seelbach et al. 1994). Coho salmon spawn in tributaries of Lake Michigan, but compared to chinook salmon and rainbow trout, much less is known about the contribution of this reproduction to coho salmon populations and fisheries (Becker 1983). Between 1976 and 1979, Carl (1982) found evidence of natural reproduction by coho salmon in 25 of 60 Michigan streams surveyed. Patriarche (1980) reported that 9% of the sport catch in Michigan waters in 1979 was from natural reproduction. Brown trout stocked into Lake Michigan generally do not migrate up streams to spawn, but they may attempt to spawn on structures in the lake. There is little if any information regarding the success of brown trout spawning (Becker 1983). Whether the recruitment of these species has changed considerably since the early 1990s when the FCOs were written is unknown, in large part because lakewide monitoring of natural reproduction has not been consistent. Currently, efforts are being made to increase knowledge of recruitment mechanisms and their influences on estimates of population biomass.

## Lake Trout Rehabilitation

Efforts to restore self-sustaining lake trout populations began with the initiation of sea lamprey control, followed by the stocking of lake trout yearlings in 1965 (Holey et al. 1995). Since 1985, a Lakewide Management Plan for Lake Trout Rehabilitation in Lake Michigan (Lake Michigan Lake Trout Technical Committee 1985) has guided restoration efforts. This plan targeted annual stocking at 5.84 million fish, focused stocking efforts in habitats where rehabilitation was judged to have the best chance for success, increased genetic diversity of the stocked fish, and established total mortality limits in areas targeted for rehabilitation

(Krueger et al. 1983; Eshenroder et al. 1984; Lake Michigan Lake Trout Technical Committee 1985; Holey et al. 1995). The plan also defined areas of the lake as refuges or primary, secondary, and deferred rehabilitation zones (Fig. 14). The plan prioritized stocking efforts. Refuges received the highest priority, secondary zones the lowest priority, and deferred zones were not stocked at all. Annual mortality was not to exceed 40% except in deferred zones. Two refuges, mid-lake and northern, were created in 1984-1985 in offshore areas containing high-quality spawning habitat. The refuges were sized to encompass the home range of the fish stocked in them, and sport and commercial harvest was banned to provide maximum protection from fishing (Fig. 14). The rest of Lake Michigan was classified into zones based on the quantity of high-quality spawning habitat, historical lake trout yield from commercial fishing, and total mortality.

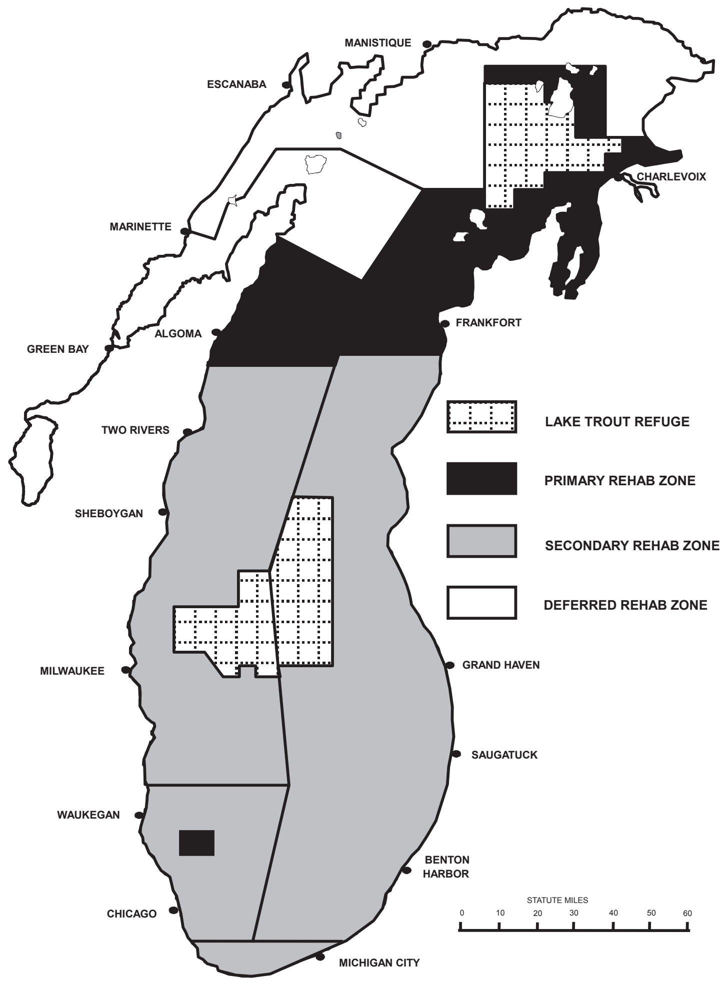


Fig. 14. Lake Michigan lake trout refuge areas, and primary, secondary, and deferred rehabilitation zones.

The number of lake trout stocked annually into Lake Michigan has been consistently about 3 million-fish short of the rehabilitation plan target of 5.84 million fish (Holey et al. 1995). Prior to development of a lake trout rehabilitation plan (1965-1984), 53% of available lake trout were stocked into zones designated as secondary or deferred, and only 9% were stocked into areas now designated as refuges. The majority (90%) of lake trout is currently stocked in either refuges (56%) or primary (34%) zones (Fig. 15). After implementation of the 1985 rehabilitation plan, more than 70% of stocked lake trout were transported by boat and released on offshore spawning reefs compared to only 27% prior to plan implementation (Holey et al. 1995).

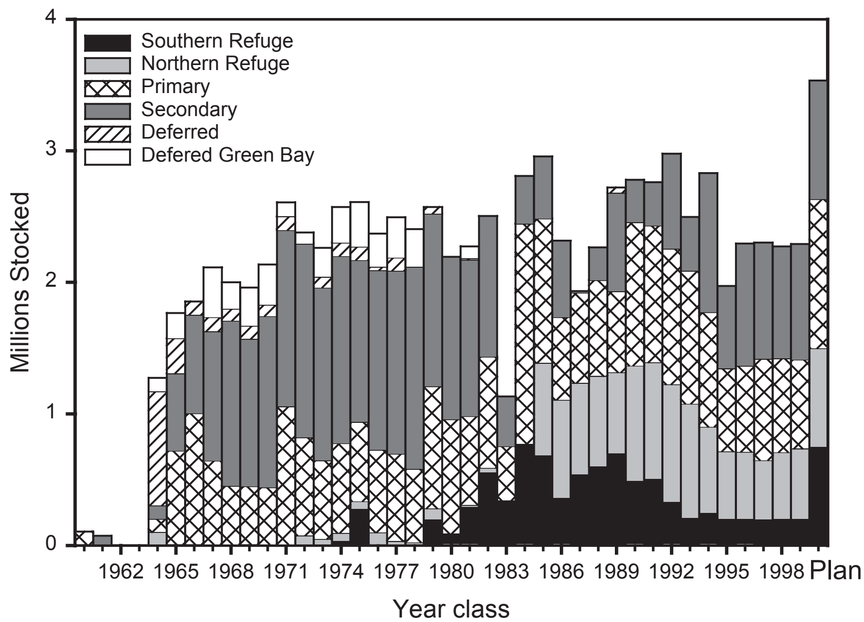


Fig. 15. Numbers of yearling-equivalent (2.44 fall fingerlings stocked = 1 yearling stocked) lake trout, by year class, stocked into Lake Michigan refuges and rehabilitation zones.

Implementation of the 1985 rehabilitation plan increased the number of lake trout strains stocked (Fig. 16) in an attempt to address the concern that genetic diversity may be limiting successful rehabilitation (Krueger et al. 1983; Eshenroder et al. 1984; Lake Michigan Lake Trout Technical Committee 1985; Burnham-Curtis et al. 1995). The Marquette strain, a shallow-water lean strain from Lake Superior, was the predominant strain stocked until 1989. After 1989, as many as six different strains were stocked annually (Holey et al. 1995). A comparison of performance among three strains was scheduled for each refuge (Lake Michigan Lake Trout Technical Committee 1985).

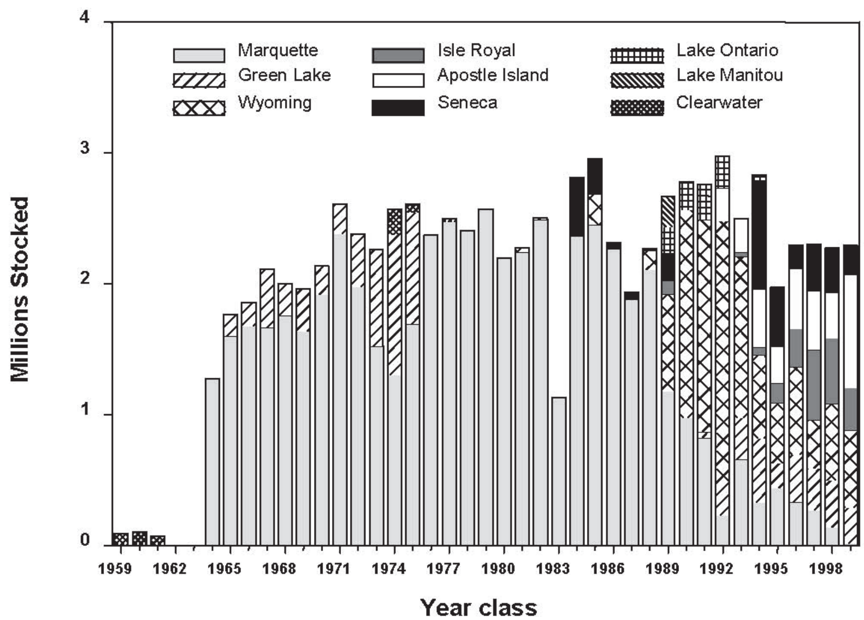


Fig. 16. Numbers of yearling-equivalent (2.44 fall fingerlings stocked = 1 yearling stocked) lake trout stocked into Lake Michigan by year class and strain.

Current abundance levels of lake trout in Lake Michigan are maintained exclusively by stocking. At many sites in southern and western Lake Michigan, the abundance of adult lake trout has increased to levels commensurate with reproducing stocks in Lake Superior (Selgeby et al. 1995), but there has been no evidence of natural recruitment to adult populations in recent years. Densities of lake trout during spawning in the northern refuge have been generally low, and densities along the western shore have been generally greater than along the eastern shore (Holey et al. 1995). The density of lake trout required to achieve recruitment of naturalized fish remains unknown.

In spite of a buildup of adult lake trout populations, evidence of natural reproduction in Lake Michigan has been sparse. During the past 30 years, fertilized eggs have been found at 19 of 25 sites sampled (Peck 1979; Dorr et al. 1981; Jude et al. 1981; Wagner 1981; Goodyear et al. 1982; Horns et al. 1989; Marsden 1994; Edsall et al. 1995), and fry have been captured at four of 15 sites sampled (Peck 1979; Jude et al. 1981; Wagner 1981; Marsden 1994). The abundances of eggs and fry are significantly lower than those observed in other systems with naturalized populations such as Lake Ontario (Fitzsimons 1995; Perkins and Krueger 1995), Perry Sound in Lake Huron, and Lake Champlain (John Fitzsimons, Department of Fisheries and Oceans, P.O. Box 85120, Burlington, Ontario, Canada, L7R 4K3, personal communication). In 1983-1989, Rybicki (1991) attributed 13% of the 1976 year class and 7% of the 1981 year class in Grand Traverse Bay to natural recruitment, as well as 4% of the 1983 year class in Platte Bay. No evidence of natural recruitment to yearling and older lake trout has been reported since the 1980s; however, assessment efforts targeting juvenile lake trout have not occurred consistently or on a lakewide basis.

After 17 years, new information is available regarding lake trout reproductive strategies and factors limiting survival. The LMC recently initiated efforts to update and revise the existing rehabilitation plan.

## Recommendations

1. Harvest expectations for salmonines should be reviewed and updated at five-year intervals.
2. The contribution of naturalized fish to salmonine recruitment should be determined.
3. Population models that increase the accuracy of estimates of yield, predator abundance, prey abundance, and consumption should be developed and continually updated to reflect our current understanding of processes influencing Lake Michigan fish communities.
4. Managers, biologists, and researchers should use a metric other than fishery yield to indicate the success or failure of management actions. Population or biomass estimates would better represent fish populations and would not be as strongly linked to the behavior of individuals harvesting fish (i.e., angler effort).
5. The components of mortality experienced by lake trout at a variety of life stages need to be determined. Information on age-specific harvest, sea lamprey marking, and abundance is needed continually to evaluate progress toward rehabilitation.
6. The rehabilitation plan for lake trout needs to be updated. The current plan is 17 years old and a considerable body of new information is available regarding limiting factors (i.e., reproductive bottlenecks). The LMC recently initiated efforts to update and revise the rehabilitation plan, incorporating this new information.

## Acknowledgments

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