12

Lake Ontario Salmonid Introductions 1970 to 1999: Stocking, Fishery and Fish Community Influences

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Introduction

The symposium on Salmonid Communities in Oligotrophic Lakes (SCOL-I) (Loftus and Regier 1972) provided insights on the stressors acting on Great Lakes ecosystem. In 2001, the Great Lakes Fishery Commission (GLFC) initiated a second SCOL symposium (SCOL-II) to synthesize new knowledge. As part of the synthesis, Great Lakes investigators submitted various working papers covering a variety of topics for use at a workshop. This is paper is one such contribution and can also be found on the internet at <http://www.glfc.org/bote/upload/salmonid introductionsstewart.doc>. The publication of the complete Lake Ontario SCOL-II synthesis is expected in 2002.

The initial introduction of salmonids into the Great Lakes was an attempt to control nuisance levels of alewife but quickly became focused on developing a multi-million dollar recreational fishing industry (O'Gorman and Stewart 1999). In early 1970s, New York State and the Province of Ontario began to establish recreational fisheries and rehabilitate lake trout by accelerating the introductions of lake trout (*Salvelinus namaycush*), brown trout (*Salmo trutta*) , rainbow trout *(Oncorhynchus mykiss*), chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*) and Atlantic salmon (*Salmo salar*). Limited stocking of kokanee salmon (*Oncorhynchus nerka*), was discontinued in 1973. The introductions initially failed to establish significant fisheries due to high parasitic sea lamprey induced mortality (Pearce et al. 1980). In the early 1980s, sea lamprey were effectively controlled (Christie and Kolenosky 1980) and the survival of all stocked trout and salmon improved. Hatchery programs in both New York and Ontario were expanded and stocking levels were increased. In the following years, activity in the recreational fishery greatly expanded. Total annual expenditures by anglers participating in Lake Ontario's recreational fisheries were $53 million (Canadian) for Ontario in 1995 (Department of Fisheries and Oceans 1997) and $71 million (U.S.) for New York in 1996 (Connelly et al. 1997). In this paper we describe the recent history (post 1970) of salmonid introductions and the offshore boat fishery. We also review and summarize information regarding major fish community influences of introduced salmonids in Lake Ontario.

Management of salmonid stocking levels

The number of salmonids stocked rapidly increased during the 1970s and 1980s (Fig. 1). In the mid-1980s, the state of New York and the province of Ontario agreed to limit stocking to 8 million salmonids annually (Kerr and LeTendre 1991) in response to concerns about the sustainability of the high predator levels, declining alewife, record fishery yields and perceived risks to the burgeoning recreational fishery (Kocik and Jones 1999; O'Gorman and Stewart 1999).

In 1992, and again in 1996, joint New York and Ontario technical syntheses and stakeholder consultations resulted in changes to stocking policy (O'Gorman and Stewart 1999; Stewart et al. 1999). Stocking levels were reduced to 4.5 million salmonids in 1996, and have been maintained at between 4 and 5.5 million annually. In 1999, the percentage of the total salmonid stocked by species was 39.2% chinook salmon, 18.8% lake trout, 17.2% rainbow trout, 12.2% brown trout, 7.2% coho salmon, and 5.5% Atlantic salmon.

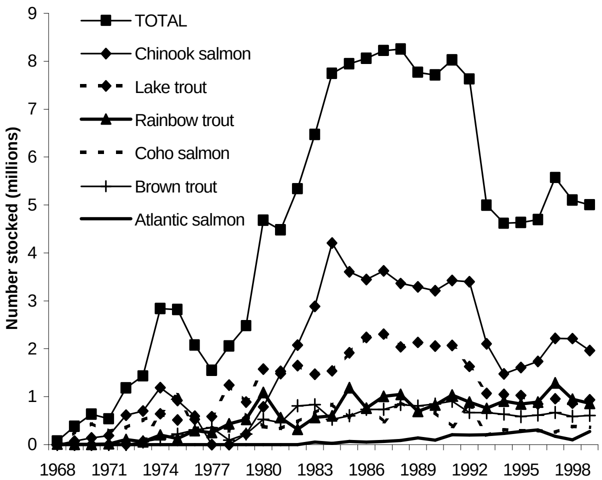

FIG. 1. Number of salmonids stocked in Lake Ontario, 1968-1999 (excludes fish stocked at a weight < 1 g).

Species stocking history

Chinook salmon

The resumption of chinook salmon stocking into Lake Ontario by New York state in 1969, and by Ontario in 1971, followed a 35-year hiatus (Parsons 1973; Kocik and Jones 1999). Despite early failed introductions in Lake Ontario, significant angling returns from Lake Michigan following introductions of Pacific salmon caused renewed interest in the other Great Lakes (Kocik and Jones 1999). Chinook salmon was initially not the dominant species stocked (Fig. 1). However, angler preference for the large fast growing chinook along with lower hatchery production costs compared to other species, resulted in an increased predominance of chinook salmon. By 1982, chinook salmon dominated the stocking of Lake Ontario salmonids. From 1982 to 1999, they represented between 32 to 54% of the annual stocking.

Stocking levels of chinook were influenced by fisheries management efforts to regulate the level of predation on alewife. Alewife is the primary prey of Lake Ontario chinook salmon (Jones et al. 1993). As a result of their high abundance and fast growth, chinook salmon account for an estimated two-thirds of the lakewide predator demand for alewives (Jones et al. 1993). Consequently, management of predator demand required management of chinook salmon stocking levels. As the mainstay of the recreational fishery and the associated tourism economies, changes to chinook salmon stocking levels were controversial. Chinook salmon stocking numbers received considerable bi-national management attention and public scrutiny (Kocik and Jones 1999; O'Gorman and Stewart 1999; Stewart et al. 1999). Stocking numbers peaked in 1984 at 4.2 million fish and ranged from between 3.2 and 3.6 million fish from 1985 to 1992. Chinook salmon stocking was reduced substantially in 1994, based on a management review in 1992 (O'Gorman and Stewart 1999), and ranged from 1.5 to 1.7 million fish annually from 1994 to 1996. Due to stakeholder demand, and a second management review (Stewart et al. 1999), stocking was increased slightly in 1997 and has ranged from 2.0 to 2.2 million fish annually from 1997 to 1999.

Lake trout

The history of Lake Ontario lake trout stocking, rehabilitation, management, and research is well documented (Schneider et al. 1983; Elrod et al. 1995; Schneider et al. 1998). Initial efforts at rehabilitation between 1953 and 1964 were abandoned, but renewed after initiation of sea lamprey control in 1971 (Schneider et al. 1983). Lake trout stocking policy has been directed at meeting management objectives for rehabilitation described in joint New York and Ontario rehabilitation plans (Schneider et al. 1983; Schneider et al. 1998). Lake trout of nine genetic strains have been stocked into Lake Ontario since 1972. The strain composition is dominated by non-Great Lake strains (6 strains), two Lake Superior strains, and a brood stock developed from mixed strains of hatchery fish that survived to maturity in Lake Ontario (Elrod et al. 1995). Lake trout stocking increased to 1.9 million fish in 1985, and was maintained above 2.0 million fish annually until 1992. Changes to stocking policy to regulate predation on alewife resulted in reductions in lake trout stocking in 1993. From 1993 to 1999 stocking of lake trout has ranged from 0.9 to 1.1 million fish annually. Management efforts have maintained lamprey mortality at low levels, restricted excessive angler or incidental commercial harvests, improved survival by increasing the proportion of Seneca genetic strain, and varied stocking practices to improve survival (Elrod et al. 1995; Schneider et al. 1998).

Rainbow trout

The rainbow trout is unique among the introduced salmonids as it represents the earliest to naturalize and has the longest history of successful introduction. Naturalized populations were established in all five Great Lakes by the early 1900s (MacCrimmon and Gotts 1972, referenced in Kocik and Jones 1999). In

Lake Ontario, there were established spawning runs in several tributaries by the 1960s (Christie 1973). Despite the presence of wild runs, rainbow trout stocking accelerated from 107,000 in 1972 to 1.1 million by 1980. From 1981 to 1999 annual stocking has ranged from 570,000 to 1.3 million fish annually representing from 6 to 23% of the total salmonids stocked. Compared to other introduced salmonids, rainbow trout stocking numbers have received less scrutiny. Encouragement of wild rainbow trout production has recently been established as a management goal (Stewart et al. 1999), however no specific stocking policies to support this goal have been developed. Much of the annual variation is due to the stocking of a diversity of life-stage (spring fingerlings, fall fingerlings, and yearlings) and the vagaries of the management of hatchery space in a multi-species fish culture program.

Brown trout

Brown trout are native to Europe but have been introduced throughout the world (MacCrimmon and Marshall 1968). Self-sustaining stream resident stocks occur in the Lake Ontario watershed but few wild brown trout exist in the main-body of Lake Ontario (Bowlby 1991). The stocking of brown trout accelerated along with other salmonids during the 1970s and 1980s and reached a peak of 0.9 million fish in 1991. From 1992 to 1999 stocking has been relatively unchanged, ranging from 585,000 to 672,000 fish annually.

Coho salmon

Much of the initial excitement and development of salmon fishing can be attributed to introductions of coho salmon (Scott and Crossman 1999; Kocik and Jones 1999). Both New York and Ontario’s renewed interest in salmonid introductions began with an initial stocking of coho salmon in 1968 (New York) and 1969 (Ontario). Coho salmon continued to dominate the province of Ontario’s stocking program until 1979. Total stocking of coho reached its peak in 1988 with the stocking of 879,000 fish. The next largest stocking of coho was in 1992 at 829,000 fish. Cost considerations resulted in the discontinuation of coho stocking by the province of Ontario from 1992 to 1996. However, because of strong public sentiment the province of Ontario resumed coho stocking in 1997. From 1993 to 1999, the number of coho stocked in New York and Ontario combined, has ranged from 196,000 to 360,000 fish annually.

Atlantic salmon

Differing and changing management objectives and policies among state, provincial, and U.S. Federal agencies has influenced the history of Lake Ontario Atlantic salmon stocking. In the recent past (post 1970), in the province of Ontario, management and stocking practices have been directed at investigating the feasibility of establishing Atlantic salmon. Stocking began in Ontario with the stocking of 1,000 fall fingerling into Wilmot Creek in 1987. From 1988 to 1995 between 28,000 and 76,000 spring yearlings and fall fingerlings, were stocked into the Credit River, Wilmot Creek and the Ganaraska River (1995 only). From 1996-1999, Ontario began to emphasize fry stocking, and between 121,000 to 249,000 Atlantic salmon fry were stocked annually. In the early years, fish from both landlocked and anadromous strains were stocked. Beginning in 1991, all Atlantic salmon stocked by the province of Ontario have been from a genetic strain of anadromous fish from the LeHave River, Nova Scotia.

In New York, the Department of Environmental Conservation program evolved from an initial rehabilitation emphasis beginning in 1983, to an increased emphasis on the establishment of a trophy sport fishery (Abraham 1988). Beginning in 1996, the U.S. Fish and Wild Service initiated limited stocking to investigate the survival and growth of stocked Atlantic salmon in selected New York tributaries. The first stockings (post 1970) of Atlantic salmon by New York were in 1983, and from 1983 to 1990 annual stocking numbers ranged from 25-53,000 fish. From 1991 to 1999 stocking increased to between 98,000 and 302,000 Atlantic salmon yearlings and fingerlings annually. New York stocked Atlantic salmon originate from four distinct landlocked strains (Little Clear Lake, Grand Lake, Lake Memphremagog, and Sebago Lake) and one anadromous strain (Penobscot River, MN).

Salmonid fisheries

The salmonid fishery is comprised of several components: an offshore-boat fishery; a lakeshore fishery; and a tributary fishery. The only fishery that is consistently monitored is the offshore boat fishery, which is thought to represent one-third to one-half of the total recreational fishing effort and harvest (Savoie and Bowlby 1991; T. Eckert, personal communication, New York Department of Environmental Conservation, Cape Vincent, N.Y. 13601).

Total annual fishing effort in the offshore boat fishery ranged from 2.2 to 4.4 million angler-hours from 1985 to 1995 (Fig. 2), with 70% of the fishery effort occurring in New York waters (Stewart et al. 2002). Fishing effort increased over the period from 1985 to 1990, but declined to about half the 1990 peak level by 1995 (Fig. 2). Total annual harvest ranged from 153 to 548 thousand fish (Fig. 2) with 58% of the harvest being from New York waters and 42% from Ontario (Stewart et al. 2002). Harvest peaked in 1986 and declined thereafter (Fig. 2).

The species composition of the harvest, in order of dominance was chinook salmon, rainbow trout, lake trout, brown trout and coho salmon (Stewart et al. 2002). Atlantic salmon harvest has been limited to several hundred fish (less than 1% of the total harvest) and will not be considered further. Harvest generally declined from 1985 to 1995 by 2 to 4-fold for all species but trends varied somewhat in New York and Ontario (Fig. 3). Chinook salmon harvest declined from a high of 224,000 in 1986 to 53,000 by 1995. Rainbow trout harvest declined from a high of 120,000 in 1988 to 40,00 fish by 1995. Lake trout harvest declined from a high of 121,000 in 1985 to 28,000 by 1995. Brown trout harvest declined from a high of 79,000 in 1986 to 28,000 by 1995. Coho salmon harvest showed the largest decline from a high of 46,000 in 1986 to 6,000 fish by 1995.

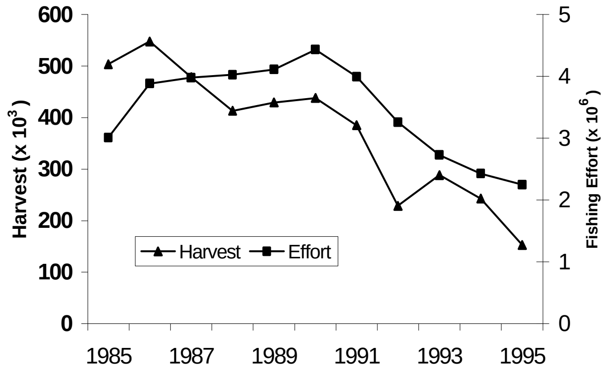

FIG. 2. Total annual fishing effort and harvest of salmonids in the offshore boat-fishery in Lake Ontario for the water of New York and Ontario combined, 1985-1995 (redrawn from table in Stewart et al. 2002).

Commercial versus recreational fishing yields

Historical commercial fisheries in the U. S. and in western and central Canada waters relied on stocks of ciscoe, lake whitefish, and lake trout. These stocks and their associated fisheries had collapsed or were greatly reduced by the mid-1940s. (Christie 1973). In eastern Lake Ontario commercial fisheries persisted. Their longevity can be attributed to lake whitefish stocks, that persisted through the 1950s and by increased reliance on warm-water species (Christie 1973). The modern commercial fishery continues to be concentrated in the nearshore waters of the northeastern part of Lake Ontario. Harvest is comprised of 15 to 20 species dominated by warm-water species (American eel, walleye, yellow perch, brown bullhead) and lake whitefish.

The commercial fishery yielded 1,050 mt of fish in 1985, but by 1995 yields had declined to 600 mt (Fig. 4). By comparison, yields from the salmonid boat-fishery peaked at 2,600 mt in 1987 and declined to 824 mt in 1995 (Fig. 4). Recreational boat-fishing yields exceeded commercial fishing yields in all years.

Examination of long-term commercial catch statistics has provided much of our understanding of early fish community structure and function (Christie 1973). Fishery yields have been used to assess changes in system productivity and food-web dynamics (Matuszek 1978; Leach et al. 1987; Loftus et al. 1987). The combined recreational and commercial yields from 1985 to 1995, expressed on an area basis ranged from 0.7 to 1.8 kg/ha. Recreational fishing yields reported in this study do not include harvests from large unsurveyed shore and tributary fisheries. Including these fisheries would result in yields at least twice as high as those documented. Matuszek (1978) determined that the maximum sustained average annual yield from historical Lake Ontario commercial fisheries from 1915 to 1929 was 1.25 kg/ha. Clearly, current fish yields far exceed historical maximums. The extremely high yields in the last decade, derived primarily from hatchery supported recreational fisheries, has no historical precedent.

Influences of introduced salmonids on the fish community

An examination of the fish community influences of introduced salmonids in Lake Ontario must consider various temporal and spatial scales. Spatial scales of influences range from effects of migratory salmonids on individual stream ecology (Kocik and Jones 1999 and references therein), to impacts on unique eco-regions such as the outlet basin of eastern Lake Ontario (Christie et al. 1987a; Casselman and Scott 1992), to whole-lake food-web impacts (Jones et

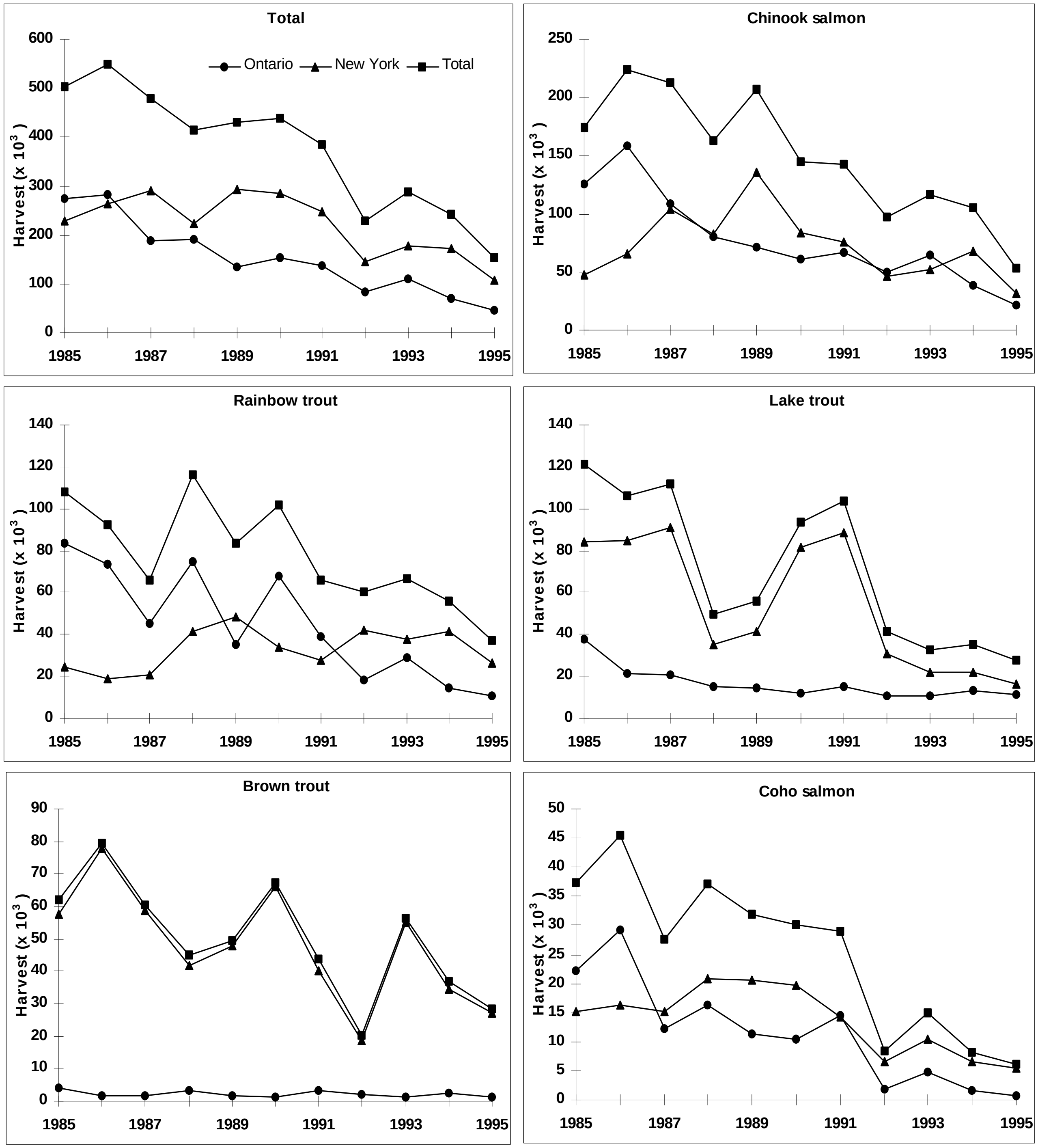

FIG. 3. Total annual Lake Ontario salmonid boat-fishery harvest and annual species-specific harvest for New York and Ontario, 1985-1995 (from Stewart et al. 2002).

al. 1993; Rand et al. 1994; Rand and Stewart 1998a; Rand and Stewart 1998b). Similarly, impacts of introduced salmonids have been investigated at the level of individual year-classes (Jones and Stanfield 1993), multi-species trend analysis (Christie et al. 1987a, O'Gorman et al. 1987) and longer-term impacts of ecosystem and food-web restructuring (Christie et al. 1987b; Eschenroder and Burnham-Curtis 1999).

Despite the diversity of investigations, we believe only two major biotic influences are evident: direct and indirect effects on fish communities through predation on alewife and smelt; both positive and negative influences on the persistence and restoration of native salmonids. A third influence, although not strictly biotic, but a consequence of the stocking of large numbers of hatchery exotics into a perturbed fish community, is the loss of an ecological paradigm on which to base fish community management.

Predation effects

Stocking of salmonids resulted in rapid build-up of predator levels through the 1970s and early 1980s (Fig. 1). Lake-wide harvest rates of chinook salmon, rainbow trout, lake trout, brown trout, and coho salmon in the offshore recreational fishery peaked in 1985 or 1986 and declined thereafter (Stewart et al. 2002). Index gillnet catches of lake trout in U.S. waters reached their highest level in 1986 and remained high (Elrod et al. 1995). In Canadian waters, the build-up of lake trout was 3-4 years later (Elrod et al. 1995) corresponding to a 3-year lag in the initiation lake trout stocking by Ontario.

Earliest available data suggest that prior to the build-up of predator levels (i.e. pre-1985), alewife and smelt were regulated by intraspecific and interspecific competitive interactions, cannibalism, and weather (Smith 1968; Christie 1973; Christie et al. 1987a; O'Gorman 1974; O'Gorman et al. 1987; Smith 1995; O'Gorman and Stewart 1999). The increasing importance of predation by introduced salmonids and other piscivores was recognized but it was not considered to be a dominant influence (Christie et al. 1987a; O'Gorman et al. 1987).

The diet of salmonids in Lake Ontario is comprised almost entirely of smelt and alewife (Brandt 1986; Rand and Stewart 1998a; Lantry 2001). By the late 1980s and through the 1990s the impact of predation on alewife and smelt became more evident (O'Gorman and Stewart 1999; Casselman and Scott 1992), although it was confounded with declines in

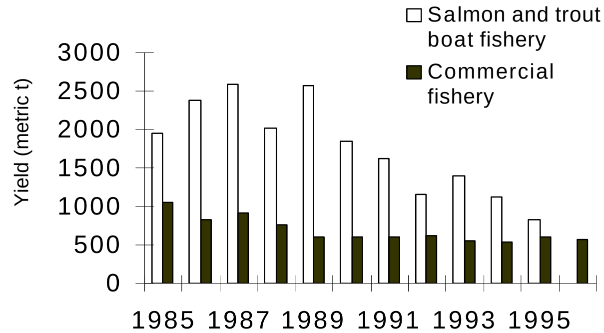

FIG. 4. Lakewide yields from Lake Ontario's New York and Ontario angling boat fishery for salmonids and from Ontario's commercial fishery, 1985-1996. The total boat-angling harvest was not measured in 1996.

nutrients and zooplankton production (Millard et al. 1996; Rudstam 1996). O'Gorman and Stewart (1999) observed that biomass of adult alewife caught in bottom trawls was 42% lower from 1990 to 1994 than from 1980 to 1984. In the outlet basin of eastern Lake Ontario, bottom trawls catches of alewife and smelt have been variable, but declined to extremely low levels beginning in 1993 (OMNR, unpublished data). Regional variation in the timing and extent of prey fish decline is to be expected and bottom trawling catches can be influenced by changed fish distribution. Less equivocal are whole-lake hydroacoustic estimates, which demonstrate a severe and persistent decline in offshore smelt and alewife numbers throughout the 1990s (Fig. 5). We contend that smelt and alewife numbers remained low throughout the 1990s due primarily to high levels of predation by introduced salmonids.

The suppression of alewife and smelt in Lake Ontario during the late 1980s and 1990s was associated with a number of fish community changes. The alewife is considered the dominant biotic influence on Lake Ontario fish communities (O'Gorman and Stewart 1999; Stewart et al. 1999, and reference therein). However, many of the food-web interactions attributed to alewife (for example, predation on fish larvae, competition with other planktivores, and their importance in the diet of trout and salmon) also apply to rainbow smelt (Brooks 1968; Christie 1973; Nepszy 1977; Brandt 1986; Loftus and Hulsman 1986). Alewives are ubiquitous in their distribution while rainbow smelt tend to inhabit deeper and colder water. Both species exhibit large-scale seasonal re-distribution between the offshore and nearshore. The abundance, distribution and ecology of these two species result in important interactions with

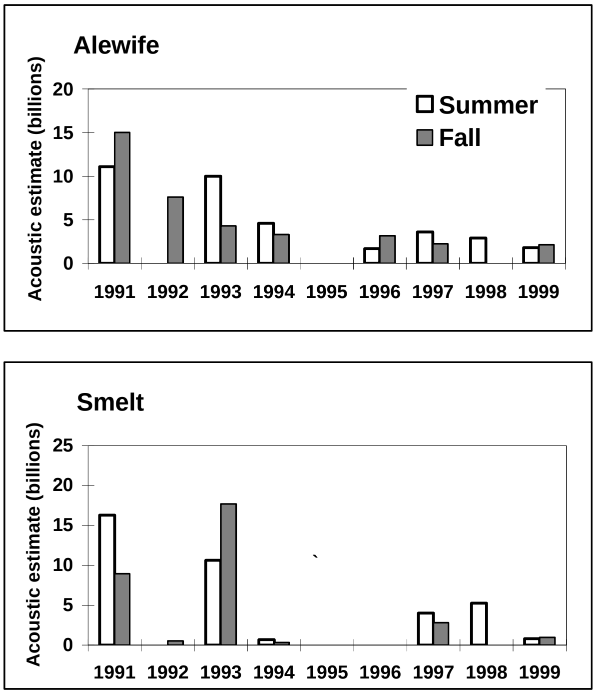

FIG. 5. Whole-lake acoustic estimates of abundance (number of fish) for alewives and smelt in Lake Ontario, 1991-1999.

virtually all offshore fish species and many inshore fish species. Coincident with the decline of alewife and smelt there was an increase in natural reproduction of lake trout, an increase in offshore abundance of native three-spine stickleback, a recovery of native lake whitefish stocks, and some improvements in native populations of yellow perch, emerald shiner, and lake herring (Stewart et al. 1999). Other factors have contributed to these changes, but they are consistent with the hypothesis of a relaxation of predation and competition from suppressed populations of alewife and smelt. More recently, the loss of *Diporeia* (deepwater amphipod) in large regions of Lake Ontario, coincident with colonization by dreissenids, has reversed whitefish recovery and may impact other species (Hoyle et al. 1999).

Effects on native salmonids

The introduction of hatchery salmonids may enhance restoration of native salmonids. Atlantic salmon and lake trout were native to Lake Ontario but all native gene pools were lost. Introductions of hatchery fish raised from available gene pools are the only way to re-establish these species. Evidence suggests that a diet high in alewives result in early mortality syndrome in the offspring of lake trout and Atlantic salmon due to an inducement of thiamine deficiency (Fisher et al. 1996; McDonald et al. 1998). The suppression of alewife by introduced salmonids may increase the diversity of Atlantic salmon and lake trout diets and mitigate the loss of thiamine.

Existing rare native brook trout and potentially future stocks of wild Atlantic salmon could be negatively impacted by continued introductions of hatchery salmonids. Kocik and Jones (1999) summarized studies on the potential interactions of introduced Pacific salmonids (rainbow trout, coho salmon, and chinook salmon) on native brook trout and on the potential for Atlantic salmon restoration. Studies and field observations indicate that it is possible for native and non-native salmonids to coexist (Kocik and Jones 1999; Scott and Crossman 1999). However, all of the introduced non-native salmonids potentially compete for spawning and nursery habitat and food with introduced Atlantic salmon and native brook trout. The high abundance of non-native salmonids, and increasing naturalization, may limit the production of native brook trout and the future extent of Atlantic salmon restoration.

Historically, four species of deepwater ciscoe, *Coregonus nigripinnis, C. reighardi, C. kiyi, and C. hoyi* inhabited Lake Ontario (Christie 1972). The loss of these species has been attributed to overfishing, increased abundance of alewives and smelt, and predation by sea lampreys (Christie 1973; Smith 1968). Fish management agencies have proposed the reintroduction of deepwater ciscoe into Lake Ontario. In Lake Michigan, although cause and effect are debated, bloaters (*C. hoyi*) increased coincident with a decline in alewife and high levels of introduced salmonid abundance (Eck and Wells 1987; Kitchell and Crowder 1986; Stewart and Ibarra 1991). These conditions exist in Lake Ontario, likely favour successful reintroduction of native deepwater ciscoes, and are dependent on maintaining a high abundance of introduced salmonids.

Loss of an ecological paradigm

The initial introduction of salmonids into the Great Lakes was an attempt to control nuisance levels of alewife but quickly became focused on developing multi-million dollar recreational fishing industry (O'Gorman and Stewart 1999). In Lake Ontario, efforts to rehabilitate lake trout where renewed with increased effort to control sea lamprey. The strategy for the rehabilitation of lake trout, and later Atlantic salmon, in Lake Ontario have had strong scientific and ecological underpinnings (Eschenroder et al. 2000; Elrod et al. 1995; Ontario Ministry of Natural Resources 1995; Schneider et al. 1983; Stanfield et al. 1995). On the other hand, science-based management of the recreational sport fishery has focused only on the potential for over-stocking (Jones et al. 1993; O'Gorman and Stewart 1999; Stewart et al. 1999).

The potential for a large controlling influence of piscivores on the structure and function of the Lake Ontario fish community was recognized (Christie et al. 1987a; Christie et al. 1987b), but this has yet to influence management decision making (Stewart et al. 1999). The Lake Ontario fish community is largely comprised of a mix of exotic species that have no evolutionary sympatry. Additionally, recruitment of the dominant predator, and the associated top-down influence on fish communities (Christie et al. 1987a; McQueen et al. 1989) is largely controlled through stocking levels. As a consequence, it is difficult to apply conventional ecological paradigms or descriptions of historical fish community structures to understand or predict species interrelationships or equilibrium states (Christie et al. 1987b; Eschenroder and Burnham-Curtis 1999). This is not only a challenge to fisheries managers but also requires researchers to develop new conceptual models of fish community structure and function to guide management.

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