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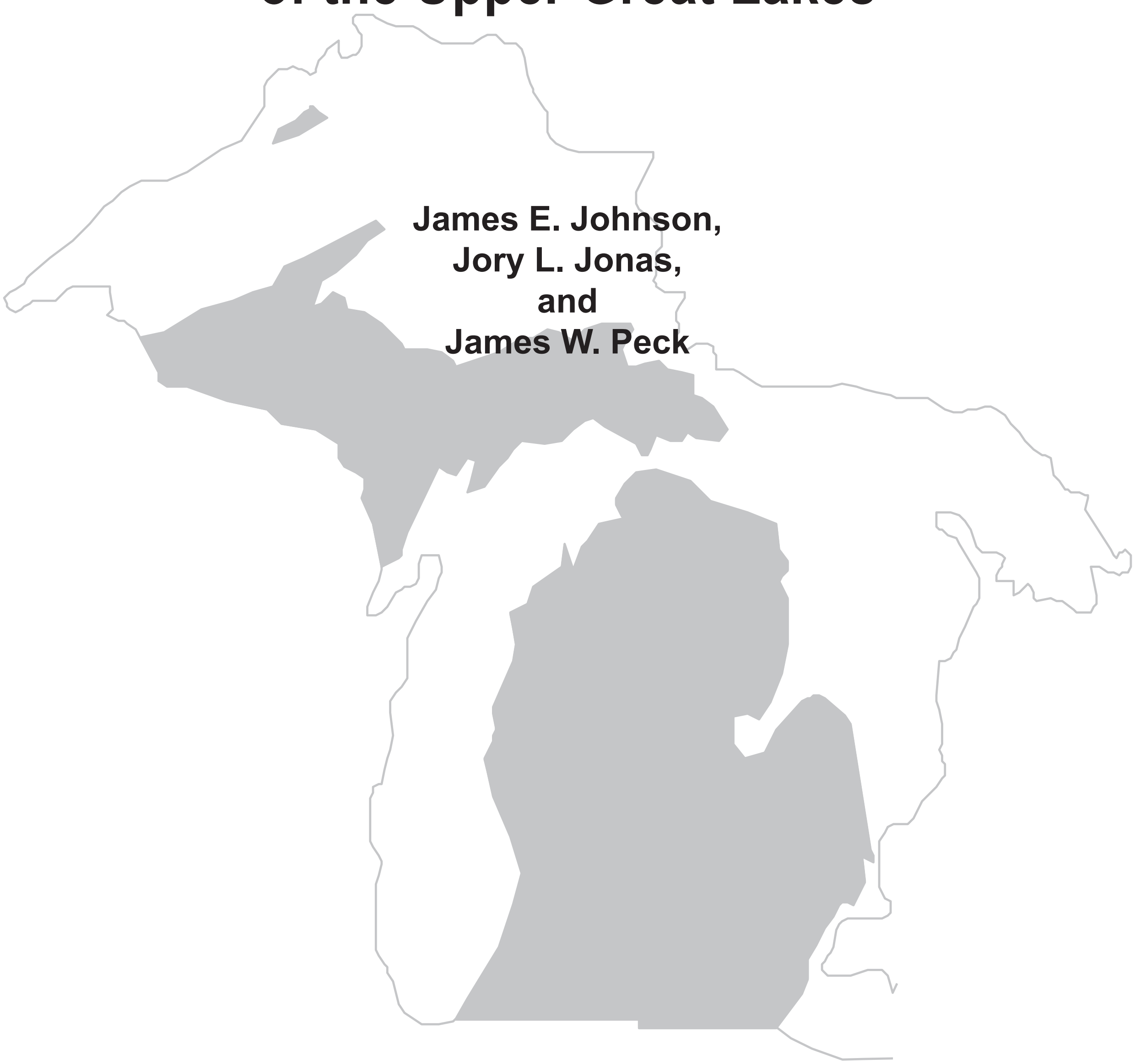
Management of Commercial Fisheries Bycatch, with Emphasis on Lake Trout Fisheries of the Upper Great Lakes



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Abstract.–We investigated the collective published record on the significance and management of commercial fisheries bycatch at both global and Great Lakes regional scales to: 1) to identify elements of Great Lakes ecosystems that are especially vulnerable as fisheries bycatch; and 2) identify opportunities to minimize incidental catch of sensitive species in Great Lakes commercial fishing gear. The majority of the world's harvestable fisheries are fully- or over-exploited, and approximately a third of the global catch is composed of bycatch and discards. Bycatch can be characterized as the incidental catch of organisms that were not targeted in a given fishing effort. Significant levels of bycatch can contribute to overharvest. Therefore, it is essential to characterize bycatch when assessing impacts of fishing. Bycatch is not always measured; failure to measure bycatch can result in underestimation of fishing mortality and thus, overestimation of quotas available for harvest. Responsible fishing practices are being encouraged worldwide and most of these efforts have focused on reducing or eliminating the amount of bycatch associated with harvest of targeted species. The magnitude of the bycatch problem is typically proportional to fishing effort. In many cases, effort exceeds what is necessary to harvest sustainable yields of target species; thus, reduction of effort is often the single most effective tool in reducing bycatch. Other methods of managing bycatch include: development and use of more selective gear, prohibiting retention of bycatch, and use of incentives and penalties in quota management. Great Lakes fisheries have mirrored the global pattern of overfishing. Recovery programs for collapsed fish populations have necessitated restrictive harvest controls. Lake whitefish *Coregonus clupeaformis* populations have recovered, but lake trout *Salvelinus namaycush* are far from rehabilitated in lakes Ontario, Erie, Michigan, and Huron. Lake trout are the native keystone species of the upper Great Lakes, are the subject of immense rehabilitation efforts, and have vulnerability similar to lake whitefish to leading gear types used in Great Lakes commercial fisheries. Efforts to limit commercial fishing to more selective gear types have been only partially successful. Bycatch of lake trout in large-mesh gill nets set for lake whitefish has exceeded lake trout harvest quotas in some management units. The selectivity of gill nets is difficult to manipulate, especially when target and nontarget fish are of similar size and overlap in spatial distribution, as is the case with lake trout and lake whitefish. Trap nets are effective in catching lake whitefish and are less lethal to the catch than gill nets. Commercial bycatch, combined with targeted fishing for lake trout (recreational and commercial) and depredation by sea lampreys *Petromyzon marinus*, has contributed to the delayed rehabilitation of self-sustaining lake trout fisheries. Thus, we conclude that the widespread use of nonselective gear types such as gill nets in Great Lakes commercial fisheries is inappropriate in an era of shared resources and ecosystem-level rehabilitation efforts.

Introduction

Bycatch has been defined as the incidental catch or harvest of aquatic life not directly targeted by fishing (Everett 1996; Romine 1996; Ackley 1997). Crowder and Murawski (1998) proposed a broad definition that includes all nontarget species, both retained and discarded, including unobserved mortalities. This wider definition is needed if all dimensions of bycatch are to be addressed (Crowder and Murawski 1998). Bycatch rose to international prominence during the 1990s with recognition that most of the world's fish stocks had become overexploited and bycatches were significant components of exploitation rates (Chopin et al. 1996; Everett 1996; Kennelly and Broadhurst 1996; Pautzke 1996; Wallace 1997; Schmitten 1998). At about the same time, resource management agencies began directing more attention at ecosystem, rather than single species, management. This changed perspective drew more attention to the total catch, rather than simply the targeted catch, and the consequent ecosystem impacts of fishing operations (Davis 1996; Everett 1996). Public interest organizations further fueled the debate by drawing political attention to the bycatch issue (Alverson and Hughes 1996).

The purposes of this paper were to: 1) investigate the collective published record on the global significance and management of commercial fisheries bycatch; 2) identify elements of Great Lakes ecosystems that are especially vulnerable as bycatch; and 3) examine principal Great Lakes commercial fishing gears and identify opportunities to minimize their incidental catch of sensitive species.

Bycatch–A Global Perspective

The Food and Agriculture Organization of the United Nations (FAO) has concluded that the majority of global fisheries resources are either fully- or over-exploited (FAO 1995). Approximately a third of this global catch is composed of bycatch (Alverson et al. 1994). Catch of nontarget species can have negative implications at population, community, and ecosystem levels (Davis 1996; Everett 1996; Crowder and Murawski 1998). Bycatches of protected species of seabirds (Atkins and Heneman 1987; Lanza and Griffin 1997), mammals (Lien 1996; Van Waerebeek et al. 1997), and protected fish species are all serious concerns (Crowder and Murawski 1998).

Impacts of bycatch take several forms. Hall (1996) suggested the following classification of bycatch based on the level and type of resource impact:

1. Critical overfishing: bycatch of species that are in danger of extinction.

2. Not sustainable bycatches: species predicted to decline under the current level of bycatch.

3. Sustainable bycatches: bycatches that do not result in population declines.

4. Not biologically significant: bycatches that are so low that they are considered negligible.

5. Bycatches of unknown level: There are no data on abundance or survival rates of bycatch.

6. Ecosystem-level impacts: A complex of species, or large biomass, is removed that may cause alterations of the system (for example, removal of a keystone predator or alteration of predator to prey ratios).

7. Charismatic bycatches: bycatch of species on which society places high value; that value may be independent of the level of impact by the fishery on the species or its associated ecosystem (for example, whales, loons, or otters).

If bycatch could be released unharmed, then it could be readily managed through regulation of possession. However, most fishing techniques produce some level of mortality on the bycatch. The determination of number or pounds of fish available for harvest requires an accurate accounting of all forms of fishing-induced mortality. The mortality factors attributable to bycatch include (Alverson and Hughes 1996; Chopin et al. 1996; Perret et al. 1996):

- Mortality associated with fish killed in the gear and discarded.
- Mortality associated with fish injured, but not captured, by fishing gear.
- Delayed mortality associated with fish captured live and released from gear.
- Mortality associated with predation after escape or release.
- Mortality associated with ghost nets.

The term "ghost nets" refers to abandoned, or lost, fishing gear that can continue to capture or injure fish for months or years. This problem is increasing because of the recent development of very durable materials, such as nylon and stainless steel (Natural Resources Consultants, Inc. 1990; Laist 1996; Kaiser et al. 1996).

Bycatches are seldom reported or quantified, and are thus not accounted for, in most estimates of fishing-induced mortality (Chopin et al. 1996). By causing underestimation of fishing mortality, unreported bycatch can cause overestimation of harvestable surpluses and ultimately lead to overharvest of stocks. Quantification of all sources of fishing mortality and minimization of resource waste are needed to optimize harvest strategies (Chopin et al. 1996).

In response to heightened awareness of bycatch and its contributions to diminishing fish stocks worldwide, the FAO prepared an international "Code of Conduct for Responsible Fisheries" (FAO 1995; Everett 1996). In this report, the FAO recommended *"States…and management organizations should…adopt appropriate measures, based on the best scientific evidence available, which are designed to maintain or restore stocks…. Such measures should provide…that:*

- *biodiversity of aquatic habitats and ecosystems is conserved and endangered species are protected;*
- *…waste, discards, catch by lost or abandoned gear, catch of non-target species, both fish and non-fish species, and impacts on associated dependent species are minimized, through measures including, to the extent practicable, the development and use of selective, environmentally safe, and cost effective fishing gear and techniques."*

The FAO report further urged that the *"…Fishers should cooperate in the development of selective fishing gear and methods. In order to improve selectivity, States should, when drawing up their laws and regulations, take into account the range of selective fishing gear, methods, and strategies available to the industry. …use of fishing gear and practices that increase survival rates of escaping fish should be promoted."* (FAO 1995).

Bycatch quantity is proportional to fishing effort, and there is growing recognition that global fishing effort exceeds that necessary to harvest sustainable yields of fish (Alverson et al 1994; Everett 1996). In certain fisheries, a reduction of effort levels is regarded as the single action that would provide the greatest reduction in bycatch and discard problems (Everett 1996). Methods that have been employed by the various United States marine regional fishery management councils to reduce bycatch include: Mesh size restrictions; gear restrictions; time and area closures; prohibiting retention; bycatch limits and quotas that, when triggered, close fisheries; improved release methods; escape holes in traps; prohibition of gear types such as gill nets; allocation of harvest opportunities to more selective gear types; public dissemination of individual vessel bycatch rates to increase peer pressure; incentives (enhanced harvest opportunities) for use of clean gear types; and extensive onboard monitoring (Pautzke 1996; Thomson 1996). Turtle excluder devices and finfish bycatch reduction devices, which employ larger mesh openings, windows, and sorting grates, have been effective in reducing trawl bycatch (Harrington and Vendetti 1996; Branstetter 1997).

Development of Great Lakes Commercial Fisheries and Emergence of the Bycatch Issue

As with marine fish stocks, the evolution and expansion of fishing gear and effort on the Great Lakes resulted in progressively greater exploitation, and subsequent declines or collapses, of key fisheries (Oosten et al. 1946; Berst and Spangler 1972; Lawrie and Rahrer 1972; Van Wells and McLain 1972; Brege and Kevern 1978; Baldwin et al. 1979; Eshenroder et al. 1992; Brown et al. 1999). In the Great Lakes, however, effects of invading sea lampreys, alewives *Alosa pseudoharengas*, and other nuisance nonindigenous species, combined with locally significant problems (i.e. water pollution), exacerbated effects of over-fishing; (Cobel et al. 1990; Eshenroder et al. 1992; Brown et al. 1999; Hansen 1999).

Prior to European settlement, fish were a staple for native peoples but fish harvests were too little, and fishing methods too primitive, to affect Great Lakes fish stocks (Lawrie and Rahrer 1972; Waters 1987; Doherty 1990; Brown et al. 1999). In the early 1800s, European settlers principally fished with seines in shallow, inshore areas (Brege and Kevern 1978; Brown et al. 1999). Thus, in the earliest days of the commercial fisheries, bycatch was not a significant Great Lakes fisheries issue. Demands on fish stocks increased dramatically in the post-settlement period, however. Early settlers introduced European fishing materials and methods to the Great Lakes, made these materials available to tribal fishers, and purchased fish products from tribal fishers. Fur companies started commercial fishing enterprises on the upper Great Lakes, beginning in the 1830s on Lake Huron. As experienced fishers, Native Americans joined in this activity (Lawrie and Rahrer 1972; Doherty 1990; Brown et al. 1999; Hansen 1999). Immigrating settlers established additional fishing enterprises. With time, and their greater financial power to invest, Americans of European extraction became the dominant players in Michigan’s commercial fisheries, although people of tribal origin continued to fish (Doherty 1990; Brown et al. 1999).

During the post-settlement era, commercial fishing effort expanded approximately in proportion to the growth of the Great Lakes region’s human population. Advancements in transportation systems (canals and railroads) and processing technologies (freezing and refrigeration) opened markets in the more populated eastern states and elsewhere to Great Lakes fishery products (Brown et al. 1999; Hansen 1999). Simultaneously, fisheries evolved to progressively more sophisticated gill nets and large, deep trap nets, requiring larger, more powerful vessels to deploy and retrieve them. Linen gill net twine was replaced by the softer, more elastic cotton thread during the 1930s. Nylon; far stronger, less visible, and more durable than cotton; increased fishing effectiveness per unit of gill net effort (hereafter termed “fishing power”) two to three fold as it replaced cotton mesh in the 1940s and 1950s (Pycha 1962; Jester 1977; Brown 1999). Multifilament nylon gill nets were replaced with monofilament nets from the 1960s to present. The large-mesh gill net also increased in depth from approximately 8 ft to 12 ft, and then to 18 ft. Fishing power for lake whitefish increased by 1.8 fold with the change to monofilament twine and rose again successively with each increase in net depth, with 18-ft deep gill nets producing 1.7 times the whitefish catch rate of 12-ft deep nets (Collins 1979; Collins 1987).

The composition and abundance of fish communities in lakes Michigan, Superior, and Huron changed dramatically during the 20th century, due to this combination of increasing fishing power and changing environmental conditions (Van Oosten et al. 1946; Berst and Spangler 1972; Lawrie and Rahrer 1972; Wells and McLain 1972; Brege and Kevern 1978; Haas 1978; Baldwin et al. 1979; Eshenroder et al. 1992; Brown et al. 1999). An average of 273,000,000 ft of large-mesh gill net was fished annually in Michigan and Wisconsin waters of Lake Michigan during the period 1936-1946 (Coble et al. 1990). From approximately 1930 to 1960, total commercial harvests from lakes Michigan and Huron declined continuously from 60 million lb to 34 million lb (Baldwin et al. 1979).

Prior to their collapse, the principal commercial fisheries of lakes Superior, Michigan, and Huron were for lake whitefish, lake trout, lake herring *Coregonus artedi*, and deepwater chubs *Coregonus sp*., the latter composed of a complex of smaller-sized coregonids. Presently, the dominant commercial species is lake whitefish (Baldwin et al. 1979; Brown et al. 1999).

Lake trout became virtually extinct in lakes Huron (Berst and Spangler 1972) and Michigan (Eschmeyer 1957) and commercial lake trout harvest from Lake Superior declined from 5.8 million lb in 1900 to 503 lb in 1960 (Baldwin et al. 1979). Lake sturgeon *Acipenser fluvescens* became almost commercially extinct on all three lakes by 1900 (Baldwin et al. 1979). By 1929 most U.S. Great Lakes states had closed their commercial fisheries for lake sturgeon and by 1977 all states had closed their commercial fisheries for lake sturgeon. Commercial fisheries for lake sturgeon continue to be permitted in Canadian waters of the Great Lakes (Auer 1999).

Collapses of lake trout and declines in catch rates of lake whitefish were consequences of a combination of overfishing and depredation by sea lampreys, which had gained access to the upper lakes during the late 1930s and the 1940s (Hile 1949; Berst and Spangler 1972; Lawrie and Rahrer 1972; Wells and McLain 1972; Coble et al. 1990; Eshenroder et al. 1992; Hansen 1999). Furthermore, food web changes induced by the invasion of the Great Lakes by planktivorous alewives, rainbow smelt *Osmerus mordax*, and other species may have reduced production of native commercial species (Smith 1968; Smith 1972; Wells and McClain 1972).

The collapse of Great Lakes native fish stocks led to a call for increased harvest controls and rehabilitation programs (Smith 1968; Berst and Spangler 1972). As early as 1865, in response to concerns about overharvest and bycatch of undersized whitefish, the Michigan legislature passed Act 350, which set minimum mesh sizes for pound nets. Further mesh size restrictions for seines, and pound, trap, and gill nets, followed between 1885 and 1909 (Brege and Kevern 1978). In response to perceived bycatch mortality in deep-water trap nets, maximum depths for trap nets were set in 1934 (Van Oosten et al. 1946; Berst and Spangler 1972).

In 1968, onboard inspections of Lake Michigan gill netters revealed that an estimated 71,000 lake trout were taken incidentally in gill nets set for whitefish and chubs (Rybicki and Schneeberger 1990). In 1968 and 1969, the Michigan Natural Resources Commission issued orders that banned large-mesh gill nets and required replacement of gill nets with impoundment gear (Brege and Kevern 1978). This ban was contested by the industry and was not fully implemented until 1977. The intent of the ban was to "encourage conversion to the more selective, highly efficient, less damaging trap nets, which were considered to be compatible with the goals of lake trout restoration" (Rybicki and Schneeberger 1990). New York, Ohio, and Indiana banned the use of gill nets in 1994 (Brown et al. 1999). In 1973, the Bay Mills Indian Community, in litigation against the State of Michigan, successfully asserted that the Treaty of 1836 granted them fishing rights in parts of the upper Great Lakes and that those rights were exempt from the State's prohibition of gill nets (Doherty 1990; Brown et al. 1999). Tribal fishing rights are also exercised using gill nets in the 1842 Treaty waters of western Lake Superior (Brown et al. 1999). Large-mesh gill net fishing is permitted in Wisconsin and Ontario waters of the Great Lakes, where they are the leading gear type for lake whitefish (Brown et al. 1999).

Contemporary Commercial Fishing in Michigan's Waters of the Great Lakes

Recovery of Lake Whitefish Commercial Fisheries

By the early 1990s, the lake whitefish commercial fisheries of the Great Lakes had completely recovered and were producing catches that exceeded those of the pre-lamprey era (Ebener 1997; Brown et al. 1999). Lake trout, on the other hand, had recovered only in Lake Superior and were maintained primarily through stocking programs in the other lakes (Hansen 1999). The principal bycatch of the whitefish fishery, in lakes Huron, Michigan and Superior, in both gill nets and trap nets, during this recovery period was lake trout (Schneeberger et al. 1982; McNeil et al. 1988; Smith 1988; McNeil and deLaplante 1989; Rybicki and Schneeberger 1990; Technical Fisheries Review Committee 1992; Schorfhaar and Peck 1993; Peeters 2001; Johnson et al. 2004). Although other species (such as walleye *Sander vitreus*, channel catfish *Ictalurus punctatus*, burbot *Lota lota*, brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss*, chinook salmon *O. tshawytscha*, and common loons *Gavia immer*) are taken incidentally in the lake whitefish fisheries of the upper Great Lakes (Schneeberger et al. 1982; McNeil et al. 1988; Smith 1988; McNeil and deLaplante 1989; Schorfhaar and Peck 1993; Peck 1997; Peeters 2001; Johnson et al. 2004), lake trout are especially vulnerable to commercial whitefish gear (Schneeberger et al. 1982; McNeil et al. 1988; Smith 1988; McNeil and deLaplante 1989; Schorfhaar and Peck 1993; Peeters 2001; Johnson et al. 2004). Lake trout are the native keystone (ecologically dominant through predatory control) species of these waters (Eshenroder et al. 1995b; Krueger et al. 1995). For this reason the focus of the remainder of this paper will be the incidental catch of lake trout in commercial lake whitefish fisheries.

Ecological Role, and Recovery Needs, of Lake Trout

Before their collapse, lake trout were the keystone predator of the Great Lakes. As the chief deepwater predator at the apex of the food web, they controlled abundance and composition of lower trophic levels. By virtue of their longevity and abundance, lake trout probably exerted a stabilizing influence on Great Lakes fish communities and dampened impacts of invading species (Evans et al. 1987; Christie et al. 1987; Eshenroder et al. 1995b). Eshenroder and Burnham-Curtis (1999) argued that systems comprised of long-lived, self-sustaining, dominant piscivores are most likely to exhibit maximum sustainability, so long as piscivore yields are maintained at low levels. However, the lake trout fisheries of lakes Huron and Michigan have not recovered and are currently dominated by relatively young hatchery lake trout. The lake trout in lakes Huron and Michigan are completely dependent upon stocking; only in Lake Superior have self-sustaining lake trout populations been restored. Mortality rates in all three lakes have often reached or exceeded target rates set by the Lake Committees of the Great Lakes Fishery Commission; thus there are few areas in the Great Lakes with surpluses of lake trout available for harvest (Eshenroder et al. 1995a; Hansen et al. 1995; Holey et al. 1995). Therefore, using the bycatch classification of Hall (1996), the lake trout bycatch in lakes Huron and Michigan borders on “Critical”, is “Not Sustainable”, and produces “Ecosystem-Level Impacts” (removal of a keystone predator and alteration of predator-prey ratios).

For restoration to succeed, lake trout survival must be high enough to generate multiple year classes of spawning-age fish in sufficient abundance to foster reproduction. For that to occur, total mortality should be managed such that total annual survival of lake trout remains above 55-60% (Healey 1978; Technical Fisheries Review Committee 1992; Krueger et al. 1995; Selgeby et al. 1995; Johnson et al., in press; Woldt et al., in press). The sources of lake trout mortality are: 1) natural, 2) sea lamprey predation, and 3) fishing (Eshenroder et al. 1995a; Sitar et al. 1997; Sitar et al. 1999; Johnson et al., in press; Woldt et al., in press). Of the three, only the latter two can be controlled. Sea lamprey control began in the early 1960s (Berst and Spangler 1972; Lawrie and Rahrer 1972; Wells and McLain 1972; Eshenroder et al. 1995a) and increased in coverage and sophistication over time (Schleen et al. 2003). In many Great Lakes jurisdictions, fishing has now surpassed sea lampreys as the leading source of lake trout mortality (Krueger et al. 1995; Hansen 1999; Johnson et al., in press; Woldt et al., in press). Fishing mortality, principally the result of inadequately regulated large-mesh gill net fisheries, is the cause of uncertain sustainability of Lake Superior’s lake trout rehabilitation (Hansen et al. 1995). A combination of commercial (targeted and bycatch) and recreational harvest and sea lamprey depredation is contributing to high mortality rates in lakes Huron and Michigan as well (Eshenroder et al. 1995a; Hansen et al. 1995; Holey et al. 1995; Johnson and VanAmberg 1995; Sitar et al. 1997; Hansen 1999; Sitar et al. 1999; Johnson et al., in press).

Description of Gill Nets and Their Incidental Catch

Gill nets, as their name implies, catch fish by entangling them in mesh, often by the gill areas. Fish caught by the gills may suffocate or sustain irreversible damage to the gill arches including bleeding from the gills (Haas 1978). At times, the fish are boxed aboard ship with the net and removed from the mesh later; in these cases, mortality of the bycatch approaches 100% (McNeil et al. 1988). Trap nets cause much lower bycatch mortality (Smith 1988; Schorfhaar and Peck 1993; Peeters 2001; Johnson et al. 2004) and are efficient in the capture of lake whitefish (Van Oosten et al. 1946). Yet, gill nets are favored by some fishers because they cost less, can be set and retrieved with smaller vessels and crews, can be set on a wider variety of bottom types than trap nets (Brown et al. 1999), and are less vulnerable than trap nets to ice damage.

The size of fish harvested by gill nets can be managed by fishing appropriate mesh sizes (McCombie and Fry 1960; Jester 1977; Hansen et al. 1997; Brown et al. 1999). Reductions in bycatch can be achieved by fishing gill nets on seasonal and spatial concentrations of target species (Jester 1977). However, selectivity of gill nets is low when target and nontarget fish have similar size and spatial distributions (Jester 1977), as with lake trout and lake whitefish (Jensen 1991). Lake trout, because of their relatively large toothed mouth, are more vulnerable to entanglement in a wide variety of mesh sizes than lake whitefish (Hansen et al. 1997).

From 1985-1998, the annual commercial large-mesh gill net harvest of lake trout by 1836 Treaty fishers averaged 734,495 lb (Michigan DNR, unpublished commercial harvest data, Lansing), of which 71% was taken as bycatch in gill nets when targeting other species, principally lake whitefish. The bycatch of lake trout in gill nets in Michigan's 1836 Treaty waters of the Great Lakes has commonly exceeded the computed total allowable catch (TAC) for the species (Technical Fisheries Review Committee 1992). In Wisconsin waters of Lake Michigan, gill nets accounted for approximately 35% of the whitefish harvest but 96% of lake trout incidental kill; trap nets took near 60% of the whitefish harvest but contributed only 3% of the incidental lake trout kill (Peeters 2001).

Several studies have been conducted to measure the mortality rates of lake trout captured as gill net bycatch. During the period 1972-1974, 70% of 7,670 lake trout caught incidentally in gill nets were classed as dead or moribund by Lake Superior fishermen who had agreed to record the condition of their lake trout catch as the nets were lifted (Haas 1978). McNeil et al. (1988) found survival rates of trout and salmon caught in commercial gill nets were variable by species and generally low. Less than 1% of salmon and approximately 20% of rainbow and brown trout bycatch caught in commercial gill nets in Ontario waters of Lake Huron were released alive. The percentage of lake trout judged releasable, if immediately extracted from the nets, was 11.3%, but only 7% were actually released alive, usually because of delays in getting the lake trout out of the mesh (McNeil et al. 1988; McNeil and deLaplante 1989). More recently, Gallinat et al. (1997) found 33% of lake trout caught in large-mesh gill nets in Lake Superior in good enough condition to release but these fish exhibited an additional 28% mortality during a 48-hour observation period. Total survival, including the recovery period, was 24%. An average of 64% of lake trout taken in gill nets in Wisconsin waters of Lake Michigan were judged to be in good enough condition to release (Toneys 2000).

Because many fish caught in gill nets die, the gill net catch can have lower flesh quality and bring a lower market price if nets are not lifted regularly (Brown et al. 1999). The catch of gill nets can become nearly worthless during summer if the nets are not tended for several days. A significant, but unknown, percentage of the resource is wasted each year when spoiled fish are discarded over the side of the boat. Such waste is not measured because commercial fishers only report what is sold. The wasted catch causes underestimation of fishing-induced mortality and error in computation of harvestable surpluses. In contrast, delays in lifting trap nets caused by storm events or other factors rarely cause significant losses of the nontarget fish or deterioration of the targeted species. Targeted fish from trap nets are boxed while still alive and marketed before deterioration can erode the value of the catch. From 1994 – 1998, Michigan-licensed whitefish catches commanded 46% more per pound in dockside value than tribally-licensed catches (Sea Grant 1994-1998). The state-licensed catches were almost entirely trapnetted, while approximately 74% of the Treaty catch was from gill nets.

Description of Trap Nets and Their Incidental Catch

There is no commercial harvest method that is without some risk to nontarget species, but when designed and fished properly, most bycatch from trap nets can be released unharmed (Smith 1988; Schorfhaar and Peck 1993; Nyberg et al 1996; Brown et al. 1999; Johnson et al. 2004). Deep trap nets are a variety of pound net that were first introduced to the upper Great Lakes in 1928 (Van Oosten et al. 1946). Trap nets are usually deployed with 1,000 ft or more of lead and two 100-ft wings that guide fish to the net. The leads and wings converge into a series of one or more chambers known as "hearts", which in turn lead to the "pot" (Figure 1). Typically, mesh sizes (stretch measure) for deepwater trap nets set for lake whitefish are 4.5 in in the pot, 5 in to 6 in in the hearts, and up to 16 in in the leads. The mesh is typically tarred nylon. Heavy coats of tar and/or use of heavy polypropylene twine stiffen the mesh and reduce likelihood of gilling the catch (Eshenroder 1980; Smith 1988; Schorfhaar and Peck 1993; Brown et al. 1999). Without these modifications, trap nets can gill their catch and inflict significant mortality (Roberge et al. 1986). Unlike the much older pound net design, the pots and hearts of trap nets are completely enclosed and can be fished at depths in excess of 100 ft; thus, at the time of their introduction they were sometimes referred to as "submarine" nets (Van Oosten et al. 1946). The depth of the pot has not been shown to influence bycatch mortality rates in trap nets (Van Oosten et al. 1946; Schorfhaar and Peck 1993).

Studies of trap net bycatch in the upper Great Lakes have shown that trap nets are effective in catching lake whitefish. Lake trout are also captured in trap nets, but mortality is generally much lower (Van Oosten et al. 1946; Smith 1988; Schorfhaar and Peck 1993; Toneys 2000; Peeters 2001; Johnson et al. 2004) than in gill nets (McNeil et al. 1988; McNeil and deLaplante 1989; Gallinat 1997; Johnson et al. 2004). Nontarget catches in trap nets in Lake Superior consisted mainly of sublegal lake whitefish and lake trout (Schorfhaar and Peck 1993). For the period 1983-1989, 12.2 sublegal lake whitefish were caught per lift, of which 0.07 (0.6%) per lift were killed. During the same period, the lake trout incidental catch averaged 7.19 per lift, of which 0.26 (3.7%) died each lift. An estimated 1,300 lb of lake trout incidentally caught in trap nets were classified as dead from 1983-1989 while nearby gill net fisheries caused the death of an estimated 200,000 to 300,000 lb of lake trout over the same time period. An estimated 48 lake sturgeon were captured in trap nets annually during the study with no observed mortality. Additional trap net bycatch reported in the study include coho salmon *O. kisutch*, chinook salmon, rainbow trout, brown trout, lake herring, suckers *Catostomus sp*., round whitefish *Prosopium cylindraceum*, and common loons. These other fish species were relatively uncommon in nets, but mortality rates ranged from 28% to 70%. The mortality of common loons was an identified concern in the study. The trap nets were not equipped with loon escapement windows and an average of 0.15 loons were killed per trap net lift. The study recommended that all Lake Superior trap nets have 12-in or 14-in stretch-measure tops over the hearts to allow loons to escape (Schorfhaar and Peck 1993).

Lake trout bycatch mortality in trap nets ranged from 3% to 6% in central Lake Michigan (Smith 1988). The mortality rate was only slightly higher than that reported for Lake Superior by Schorfhaar and Peck (1993); however the catch rate of lake trout in Lake Michigan was much higher than for the Lake Superior study, averaging 75 per net lift in 1985 and 1986 and frequently exceeding the catch of lake whitefish. The number of lake trout killed in the Lake Michigan study ranged from 2.3 to 5.2 per lift. Soak time (the time between lifts) was longer than usual and lake trout abundance was exceptionally high during the Lake Michigan study, which may have contributed to the higher lake trout mortality reported by Smith (1988). In northern Lake Huron, with lake trout densities similar to those of the Lake Michigan study, ranging near 75 lake trout per lift, the mortality of lake trout averaged only 1.1 per lift (Schneeberger et al. 1982).

Gear selectivity was compared in north-central Lake Huron in 1998 and 1999 by monitoring 96 trap net and 260 large-mesh gill net lifts (Johnson et al. 2004). The lake trout bycatch and number of lake trout killed per lift, respectively, averaged 16.5 and 9.8 in gill nets, and 20.9 and 2.1 in trap nets. Lake trout bycatch was significantly higher in spring and summer than in fall for both gear types. Mortality of lake trout, expressed as a ratio to lake whitefish harvested, was significantly higher in gill nets than in trap nets in each of the three seasons tested. During summer, the number of lake trout killed per 100,000 lb of lake whitefish was estimated to be 21,805 in gill nets and 5,109 in trap nets. Across seasons, gear-induced mortality on lake trout bycatch was significantly higher in gill nets (60.4%) than in trap nets (12.2%). The difference was especially pronounced during spring and fall.

There has been little research into survival rates of lake trout after their release from trap nets (Schneeberger et al. 1982). Nyberg et al. (1996) reported high survival rates for pikeperch *Stizostedion lucioperca* caught in trap nets. Of 2,299 pikeperch captured and released, 887 were recaptured at least once; six were recaptured 20 times, and one fish 39 times. Johnson et al. (2004) reported that post-capture mortality of 186 lake trout held in laboratory tanks after being removed from trap nets was 1.6%. Some of the lake trout deaths reported by Johnson et al. (2004) may have been caused by the additional stress of transport and handling en route to the laboratory.

Trap net technology continues to improve. The use of tarred mesh, stiff polypropylene, and larger mesh sizes, especially in the leads and hearts, has been effective in reducing lake trout mortality in trap nets through reducing the incidence of gilling (Schorfhaar and Peck 1993). Shoaling twine (very small mesh) is commonly used in the tops and corners of the pot to reduce gilling of lake trout (Eshenroder 1980) but this improvement has not proved to be uniformly effective (Smith 1988). The catch of common loons can be unacceptably high in unmodified trap nets. Lake Superior whitefish grounds are in close proximity to migratory staging areas and inland nesting sites of common loons, which may elevate loon catch rates there (Carey 1992; Schorfhaar and Peck 1993). Trap nets modified with larger mesh in the roofs of their hearts caught only half as many loons as unmodified nets and whitefish catch rates were unaffected by the modifications (Peck 1997). Loon-excluding modifications, however, have not been widely studied in commercially scaled fisheries (Peck 1997), and are not currently required of Michigan's trap net fisheries.

Management Options for Reducing Great Lakes Bycatch

Overfishing, particularly the overdeployment of gear, magnifies bycatch problems (Everett 1996). The gill net bycatch of lake trout in Michigan's Great Lakes has been exacerbated by the large amount of effort deployed. The problem was especially acute in Treaty waters of northern Lake Huron, where gill net effort was eventually reduced 50% to reach mortality and spawning stock biomass per recruit targets (United States District Court 2000; Woldt et al., in press; Johnson et al., in press).

For less lethal gear types, the release of lake trout and other nontarget bycatch should be required. Michigan's state-licensed commercial trap net fisheries are already required to release all lake trout and other protected species. However, requiring release of nontarget fish caught in gill nets would result in the waste of a large percentage of the gill net bycatch (Brown et al. 1999). Therefore, regulations requiring the release of lake trout should be in conjunction with conversion to less lethal gear types or other measures to ensure management goals are met.

Bycatch could be limited by setting bycatch limits or quotas that, when reached, would close a specific fishery or all fisheries for the target species. For example, when the lake trout quota for a management unit was reached, all fishing that caused a significant catch or bycatch mortality of lake trout would cease. A more effective approach would be a combination of restrictions, quotas, and incentives to minimize bycatch. For example, an increased quota for target species (e.g., lake whitefish) could be awarded to fisheries with low bycatch rates; while penalties, such as individual-bycatch-quota based closures, could be issued to those fishing nonselective gear with high bycatch rates. A combination of incentives and penalties may cause the fishers themselves to avoid bycatch problems by changing gear, releasing live bycatch, and reducing nonselective effort.

Adequate enforcement and monitoring will be essential to successful bycatch control strategies. In particular, on-board monitoring is needed to produce reliable estimates of bycatch released alive and bycatch discarded dead, neither of which are included in wholesale reports.

Conclusion

Like their marine counterparts, Great Lakes fisheries are now fished near, or in some cases beyond, sustainable levels. The overfishing of the 1930s and 1940s, in combination with invasion of non-native species, has caused ecosystem collapses in each of the Great Lakes. There are aggressive recovery efforts in place for several native species, including lake trout, walleye, and lake sturgeon. However, overharvest of lake trout, partly caused by incidental catch, particularly in gill nets, has impeded ecosystem restoration in the upper Great Lakes.

Prior to about 1960, the Great Lakes were principally exploited as commercial fisheries. Now commercial, tribal (subsistence, recreational, and commercial), and recreational fishers share these resources. Consequently, it is imperative that the fisheries be managed as shared resources for the economic and cultural benefits of each stakeholder group, while affording protection of species undergoing rehabilitation. To do so will require more sophisticated management actions to regulate both harvest and bycatch.

The widespread use of nonselective gear types such as gill nets is inappropriate in an era of shared resources and ecosystem-level rehabilitation. The current large bycatch of lake trout, for example, occurs at the expense of rehabilitation programs, ecosystem stability, and the interests of other Great Lakes stakeholders. Therefore, commercial fisheries for lake whitefish should be required to use gear that is more selective. Further research efforts should investigate opportunities afforded by new materials to further reduce the incidence of gilling of fish and entrapment of loons in trap nets. Finally, there is a need for all the resource agencies on the Great Lakes to manage bycatch in a more coordinated fashion to insure that ecosystem management goals are met.

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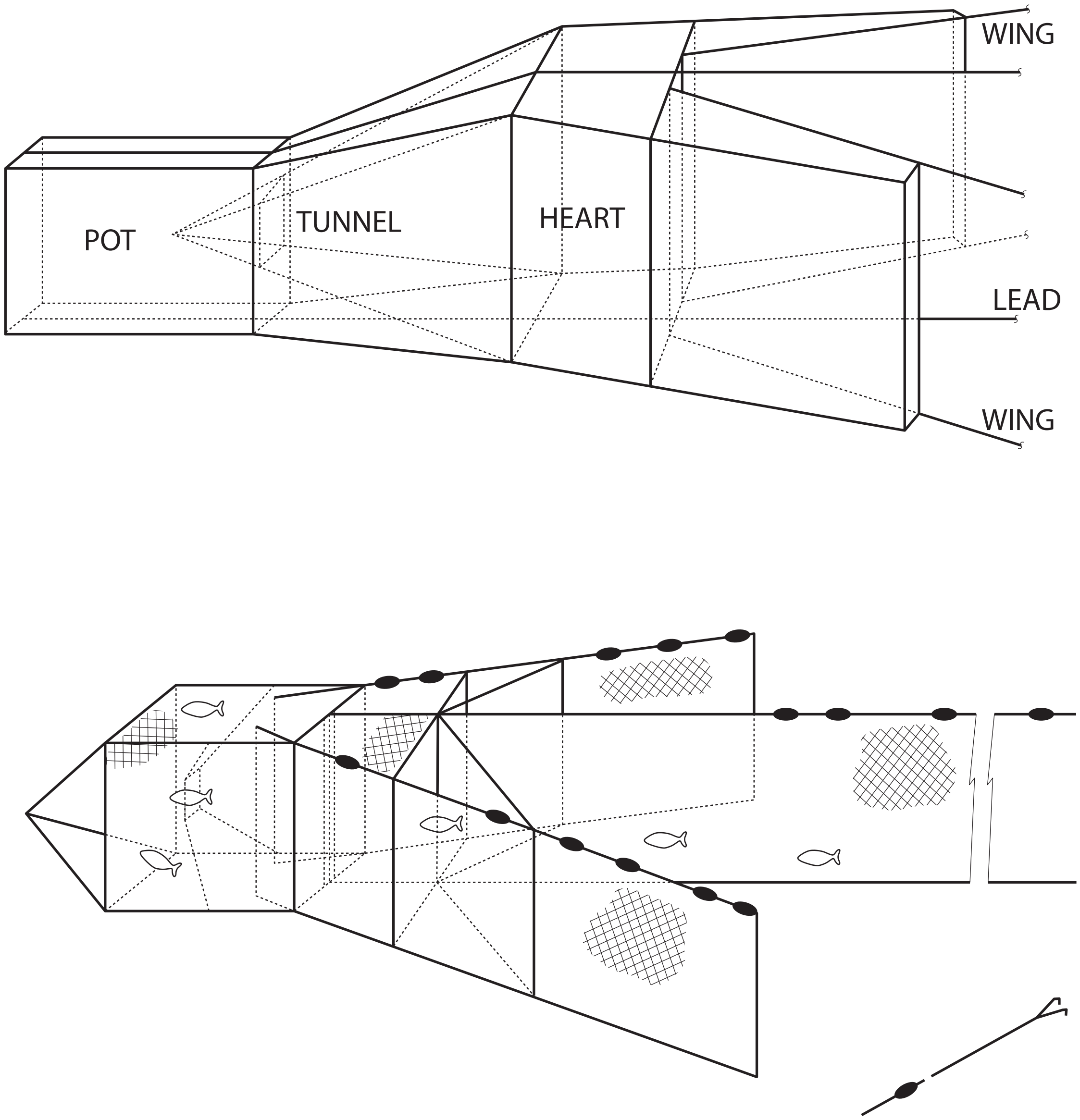

Figure 1.–Two types of Great Lakes trap nets.

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