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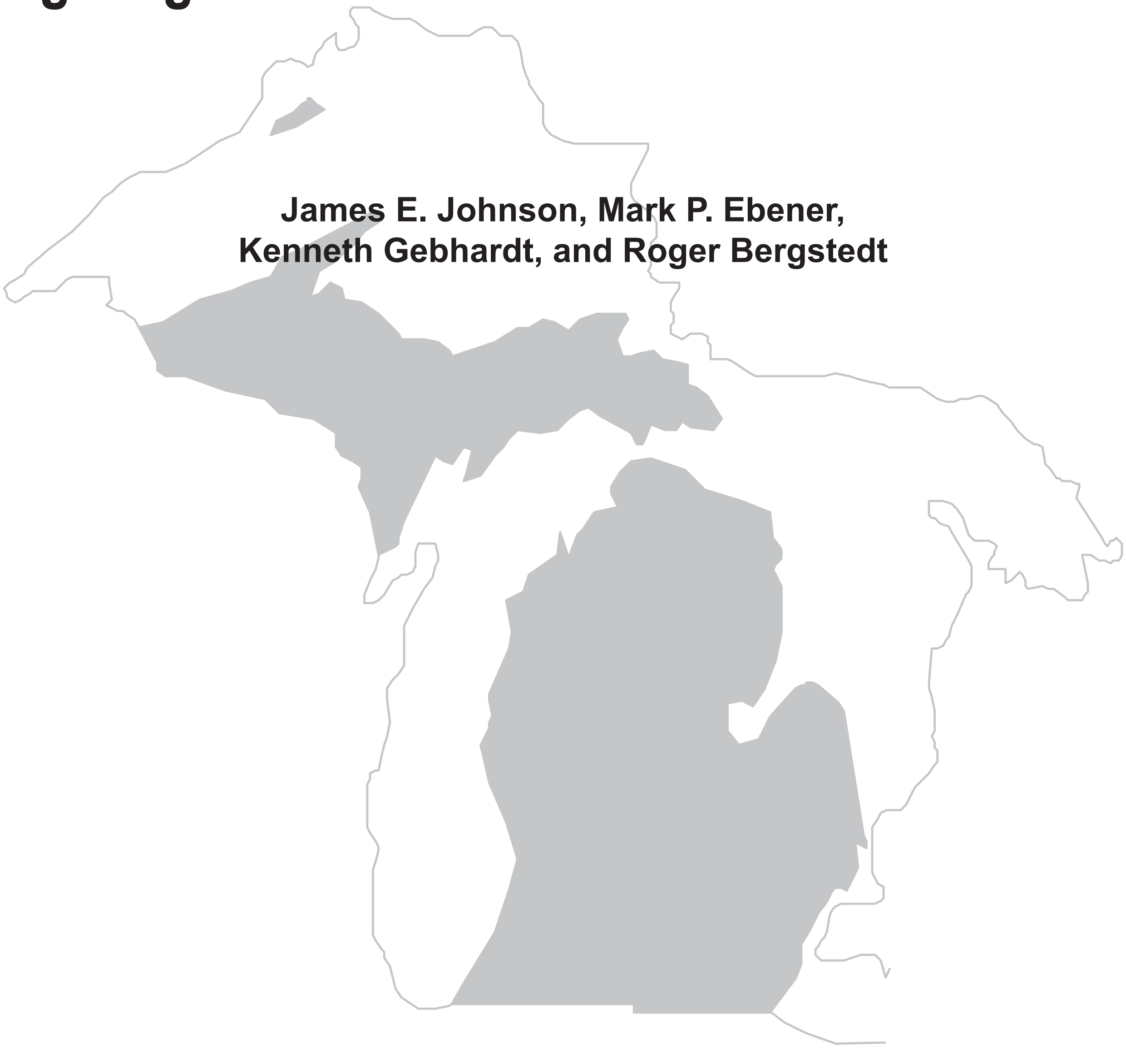

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FISHERIES DIVISION
RESEARCH REPORT

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# Comparison of Catch and Lake Trout Bycatch in Commercial Trap Nets and Gill Nets Targeting Lake Whitefish in Northern Lake Huron

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*Abstract.*–We compared seasonal lake whitefish catch rates, lake trout bycatch, and gear-induced lake trout mortality between commercial trap nets and gill nets in north-central Lake Huron. Onboard monitors recorded catches from 260 gill net and 96 trap net lifts from October 1998 through December 1999. Catch rates for lake whitefish were highest in fall for both gear types, reflecting proximity of spawning sites to the study area. Lake whitefish catch rates were also relatively high in spring but low in both gear types in summer. Lake trout were the principal bycatch species in both gears. The lake trout bycatch was lowest in both gear types in fall, highest in gill nets in spring, and highest in trap nets in summer. The ratio of lake trout to legal whitefish (the target species) was highest in summer and lowest in fall in both gear types. The high lake trout ratio in summer was due principally to low catch rates of lake whitefish. All but 3 of 186 live lake trout removed from trap net pots survived for at least two days of observation in laboratory tanks. Therefore, we estimated that post-release survival of trap netted lake trout that had not been entangled in the mesh was 98.4%. In addition, we accounted for stress-induced mortality for lake trout that were live at capture but entangled in the mesh of either gear type. Resulting estimates of lake trout survival were higher in trap nets (87.8%) than in gill nets (39.6%). The number of lake trout killed per lift was highest during summer in trap nets and during spring in gill nets. In trap nets, 85% of dead lake trout were observed to be entangled in the mesh of the pot or tunnels. Survival rates of lake trout in gill nets were higher in our study than reported by others, probably because our nets were hand lifted in a small boat. Our trap net-induced mortality estimates on lake trout were higher than those reported by others because we adjusted our estimates to account for post-release mortality caused by handling and injury. Studies such as ours should prove useful to managers developing harvest allocation options that are consistent with the need to protect nontarget populations. For example, applying our seasonal lake trout-whitefish catch ratios to a hypothetical small-boat gill net fishery, the lake trout bycatch from harvest of 100,000 kg of whitefish would equal the estimated lake trout production available for harvest in the study area for year 2002. The two trap net fisheries may have incidentally killed half this number of lake trout annually from 1995-99. Bycatch estimates are also important inputs to catch-at-age decision models used in developing rehabilitation and harvest strategies for target and bycatch species.

During the 1990s, commercial harvest of lake whitefish (see Table 1 for list of species referenced) in the upper Great Lakes exceeded that of any previous period (Ebener 1997; Brown et al. 1999). Although there are few areas in the Great Lakes with surpluses of lake trout available for harvest (Eshenroder et al. 1995; Hansen et al.1995; Holey et al. 1995; Hanson 1999; Johnson et al., in press), the principle bycatch of commercial fisheries targeting lake whitefish is lake trout (Eshenroder 1980; Schneeberger et al. 1982; McNeil et al. 1988; Smith 1988; McNeil and deLaplante 1989; Rybicki and Schneeberger 1990; Schorfhaar and Peck 1993; Gallinat et al. 1997; Brown et al. 1999; Peeters 2001; Johnson et al. 2004). Bycatch, defined as the incidental catch or harvest of aquatic life not directly targeted by a fishery (Everett 1996; Romine 1996; Ackley 1997; Johnson et al. 2004), is often associated with some level of fishing mortality.

In 2000, the five Chippewa/Ottawa tribes of Indians signatory to the Treaty of 1836, the Federal Government, and the State of Michigan entered into a Consent Decree with United States District Court for the Western District of Michigan. The Consent Decree governs allocation, management, and regulation of fishing for northern Lake Huron and parts of lakes Michigan and Superior. One element of the Consent Decree was agreement by the parties to reduce fishing-induced mortality of lake trout, particularly in commercial fisheries targeting lake whitefish. Conversion of gill net fisheries to less lethal gear types and imposition of harvest quotas were identified as strategies for reduction of bycatch mortality (United States District Court 2000).

The two principal gear types used in Great Lakes commercial fisheries are large-mesh gill nets and trap nets. Bycatch rates of the two gear types have been extensively studied (Van Oosten et al. 1946; Eshenroder 1980; Schneeberger et al. 1982; McNeil et al. 1988; Smith 1988; McNeil and deLaplante 1989; Rybicki and Schneeberger 1990; Schorfhaar and Peck 1993; Gallinat et al. 1997; Brown et al. 1999; Peeters 2001). However, there are few, if any, comparisons of lake trout bycatch in gill nets and trap nets fished concurrently for lake whitefish in the same waters. To accurately determine the number or pounds of fish available for harvest, all forms of fishing-induced mortality on both the targeted and bycatch species must be accounted for (Alverson and Hughes 1996; Chopin et al. 1996; Perret et al. 1996). Therefore, in preparation for the year 2000 treaty negotiations, a study was initiated in north-central Lake Huron to determine if a gill net fishery targeting lake whitefish could take place in an area where lake trout were being rehabilitated. Because the study area happened also to be fished by two long-established trap net fisheries, this study afforded an opportunity to examine the comparative bycatch rates of the two fishing gear types.

The objectives of this portion of the study were to: 1) describe the catch rates of lake whitefish in the two gear types by season; 2) describe the fishing-induced mortality on lake trout bycatch in the two gear types by season; 3) compare the bycatches of lake trout by gear type and season; and 4) describe the bycatch of other species in the two gear types.

## Methods

The study area included Michigan waters of north-central Lake Huron from Hammond Bay Harbor to Thunder Bay, a linear distance of 110 km (Figure 1). The study area encompassed 1,400 km$^2$ of water shallower than 75 m and was divided into three spatial sub-units of approximately equal size. Commercial fishing in the area had been restricted to trap nets since 1990. The south reaches of the study area near North Point of Thunder Bay included bedrock reefs used as spawning grounds by lake whitefish and lake trout.

### *Gill Nets*

Three Bay Mills Indian Community commercial fishers were authorized to fish up to six 305-m gangs of gill nets per day; however, only one of these individuals actually fished during the study. Each gang was composed of four 76-m long, 114-mm (stretch-measurement) mesh nets, which were 50 meshes or approximately 4.6-m deep. The mesh was composed of 0.20-mm diameter monofilament. The nets were fished out of a relatively small (6.1 m) open boat and lifted by hand. Whitefish harvest was restricted to fish > 432 mm total length, with smaller fish not legal for sale. Gill net effort was distributed among each of the three spatial units (Figure 1). Within each spatial unit, the fisher was asked to apportion his monthly effort equally between each of three depth categories: < 23 m; 23-46 m; and > 46 m. There was no maximum depth restriction on the fishing of gill nets. In order to avoid excessive bycatch of lake trout, the fisher was required to stop fishing a stratum if catch rates were 50% greater than a target catch of 15 lake trout per 305 m of gill net. In order to encourage distribution of effort to all strata, the fisher was required to move gear if whitefish catch rates were either 33% below or 50% greater than a target rate of 73 kg per 305 m of gill net (Ebener et al. 1998). The resulting gill net catch rates were therefore influenced by these restraints.

The gill net portion of the study was from 25 October 1998 to 9 December 1999. All gill net lifts were monitored by onboard observers (Table 2). Gill net fishing was interrupted by winter weather conditions on 14 December 1998, and resumed on 28 March 1999. There was no fishing from 1200 hours 6 November through 1200 hours 29 November in observance of the Chippewa/Ottawa Treaty Management Authority spawning closure period. The onboard observer recorded latitude, longitude, water depths, number of nights since the last lift, number of boxes of lake whitefish, number of lake trout, and number of other species caught in each gang. The lake trout bycatch was classified by the onboard observer as either dead/moribund or live. Lake trout were classified as dead or moribund if they were bleeding at the gills, handled by the gills, or were lethargic when retrieved. All live lake trout were released. Catch per effort (CPE) of lake whitefish was measured as boxes per lift and converted to kg per lift using the mean weight of a box of whitefish (45 kg). Numbers of lake whitefish were computed by dividing weight per lift by the mean weight of whitefish during the sampling period. Lake trout CPE was measured as number of fish per lift.

Lengths, weights, sex, and stage of maturity of lake whitefish and lake trout were recorded from a portion of the catch during most months of the study. Seasonal mean weights from these data were used to convert between numbers and weight of fish in the commercial gill net catches.

### *Trap Nets*

Two preexisting trap net operations in the study area under state permit were each allowed to fish up to ten trap nets. The pots of these nets were composed of 114-mm, 116-mm, or 117-mm stretched-measure mesh of #15 thread size, multifilament nylon. The pots ranged from 3.1 m to 9.2 m high. The 3.1-m nets were fished in fall, when fishing depths ranged less than 10 m. The hearts and tunnels (Figure 2) were constructed of the same twine as the pots but were composed of somewhat larger mesh sizes. Most leads were composed of nylon twine with mesh sizes ranging from 305 mm to 406 mm. Leads ranged from 246 to 427 m in length. The nets were fished in depths ranging from 7.2 m to 29.5 m, depending on season and fish distribution. Maximum depth was regulated by a 29.5-m State-imposed maximum-depth restriction. The nets were built with shoaling twine over the tunnels and in the corners of the pots to reduce the incidence of fish becoming caught by the gills. Most nets were recently tarred, also designed to reduce incidence of gilling.

The sampling goal was to monitor each fisher at least once per month from October 1998 through December 1999. The goal was not always attained (Table 2) because fishing ceased with the onset of winter conditions in mid-December 1998 and did not resume until mid-April 1999. Nets were lifted less frequently in summer which, combined with lower sampling frequency due to scheduling conflicts, caused sample sizes in summer to be low. There was no trap net fishing in November 1999 because of a State-imposed spawning closure.

The onboard observer recorded latitude, longitude, pot height and mesh size, lead length and mesh size, water depths at the pot, number of nights since the last lift, number of boxes of lake whitefish, number of lake trout, and number of other species caught in each net. Similar to the gill net methodology, lake trout were classified by the observer as live or dead/moribund. Capture mode for each lake trout was recorded as either "gilled" (entangled in pot or tunnel mesh), or "pot" (loose in pot). Lake whitefish harvest was restricted to fish > 482 mm. State regulations required release of whitefish below the length limit. Commercial harvest of lake trout is prohibited by the State, thus all lake trout were released except for those used to estimate post-release survival. The CPE of lake whitefish was measured as boxes per lift and converted to weight per lift using the mean weight of a box of whitefish (45 kg). Numbers of lake whitefish were computed by dividing weight per lift by the mean weight of whitefish during the sampling period. Lake trout CPE was measured as number of fish per lift. Lengths, weights, sex, and stage of maturity were recorded from samples of lake whitefish but not lake trout during trap net monitoring, therefore, mean lake trout weights from gill net monitoring were used to convert from numbers to weight of lake trout in the trap net catches.

To estimate survival of lake trout released from trap nets, Hammond Bay Biological Station staff observed post-capture survival of 109 and 77 apparently healthy lake trout taken from trap nets in the study area during spring and early summer in 1999 and 2000, respectively. Only lake trout that were obviously moribund or injured were rejected from the sample. These fish were transferred from study-area trap nets to coolers and transported by boat and truck to Hammond Bay Biological Station laboratory tanks filled with Lake Huron water. Most of the fish were surgically implanted with temperature-recording tags as part of an unrelated study and all were held for at least two days after capture before being released.

### *Data Analysis*

Gallinet et al. (1997) found that on average 28.4% of live lake trout removed from gill nets died within 48 hours; thus, the number of dead lake trout per gill net lift was computed as number of dead lake trout + (0.284 × number live lake trout released). Likewise, the number of dead lake trout per trap net lift was computed as number of observed dead (gilled or loose in the pot) lake trout per lift + (0.284 × number live lake trout released that had been gilled in the trap net mesh). In addition, the number of surviving lake trout per trap net lift was adjusted using the post-capture survival observations at Hammond Bay Biological Station.

Lake whitefish catch rates were expressed as geometric means with confidence limits derived by $\log_{10}$ transformation (Fowler and Cohen 1990). $\mathrm{Log}_{10}$ normalized lake whitefish catch rates were compared using, in most cases, analysis of variance (ANOVA) and Sheffe post-hoc analysis of differences between multiple means using SPSS for Windows Release 11.5.0. Sixteen percent of lifts, both gear types combined, produced no lake trout and the lake trout catch rates were too strongly skewed to be log normalized. Thus nonparametric tests were used to compare mean CPEs of lake trout and ratios of lake trout and lake whitefish CPEs.

The study results were partitioned into three seasonal periods, within which lake whitefish gill net CPEs were similar, based upon analysis of variance of $\log_{10}$ normalized CPEs. Monthly means were not significantly different (ANOVA, $P = 0.245$) and confidence intervals of the transformed gill net catch rates were similar for March, April, May, and June. Monthly means differed (ANOVA, $P < 0.05$) but confidence intervals of the gill net catch rates appeared similar (Figure 3) among the months July, August, and September. Thus, months prior to October were pooled into either spring or summer periods. October, however, was a transition month, with a gill net catch rate intermediate between those of September and November. Gill net CPE during the first week of October was similar to that of the summer period. Thus, data from the first week of October were pooled with the summer period and those of the remainder of the month combined with November and December to produce a third, fall period. Monthly means differed (ANOVA, $P < 0.05$) but confidence intervals for the resulting fall months overlapped with each other (Figure 4). Trap net monitoring was less intensive than gill net monitoring, resulting in smaller sample sizes (Figure 5). For comparison purposes, the trap net data were pooled into the same time periods as the gill net data.

A lake trout bycatch index was computed for each trap net and gill net lift as the ratio of number of lake trout to number of lake whitefish. First, lake whitefish catches were converted from weight to number per lift. Because 1.4% of lifts contained no lake whitefish, before computing the index one lake whitefish was added to every lift to avoid division by zero. This index was used as a test statistic for comparing within-season differences in lake trout bycatch between gear types.

## Results

### *Catch Rates by Species – Whitefish*

In both gear types, catch rates of lake whitefish were highest in fall and lowest in summer (ANOVA and Sheffe post-hoc analysis, $P \leq 0.027$, Table 3). By November, 79% of lake whitefish in the gill net catch were mature; of those, 79% were identified as ripe (in spawning condition) or spent (Table 4). Fishing depths of both gear types were significantly shallower in fall than spring or summer ($P < 0.01$, Table 5), reflecting the depths at which lake whitefish were spawning. Mean fishing depths were deeper for gill nets than trap nets in spring and summer, probably due to the 29.5 m depth restriction governing trap nets.

### *Catch Rates by Species – Lake Trout*

As with lake whitefish, lake trout catch rates varied significantly by season (Kruskal-Wallis nonparametric test, $P < 0.001$) and were lowest in fall in both gear types (Table 3). The gill net CPE for lake trout was significantly lower in summer than in spring (Mann-Whitney nonparametric test, $P < 0.001$), but trap net CPE of lake trout was similar in spring and summer ($P = 0.48$, Table 3).

### *Gear-induced Mortality Rates by Species and Gear*

In 1999, only three of the 109 trap netted lake trout (2.8%) died following transport to laboratory tanks. Even though 63 underwent a surgical procedure to implant temperature-recording tags for an unrelated study, no further mortalities were observed. In spring of 2000, 77 trap netted lake trout were transported to the Hammond Bay Biological Station, implanted with tags, and released with no observed mortality. All fish were observed for at least two days after capture before being released. Thus, a total of 186 trap netted lake trout were observed, of which 3 (1.6%) died during the observation period.

Lake trout catch and estimated number of lake trout killed are given in Tables 6 and 7 for the gill net and trap net fisheries.

### *Comparison of Seasonal Lake Trout Bycatch by Species and Gear*

Lake trout mortality rates were significantly higher in gill nets (60.4%) than in trap nets (12.2%) over the study period (t test, $P < 0.001$, Table 7). For both gear types, the percent of catch composed of lake trout was highest in summer (31%) and lowest in fall (1.6%, Table 8). During summer, lake trout composed 30% of gill net and 33% of trap net catches. Estimated number of lake trout killed per lift varied by season (Kruskal-Wallis test, $P < 0.001$) in both gear types, with the highest number killed per gill net lift in spring and the highest per trap net lift in summer. For both gear types the number of lake trout killed per lift was lowest in fall (Tables 6 and 7).

Lake trout bycatch, expressed as a ratio of number of lake trout per whitefish+1 caught per lift, differed by season (Kruskal-Wallis test, $P < 0.001$). For both gear types, the highest lake trout bycatch ratios were in summer and the lowest in fall (Table 9). The number of lake trout killed per whitefish+1 harvested was significantly higher in gill nets than in trap nets in each of the three study periods (Mann-Whitney U, $P < 0.01$, Table 9).

### *Other Bycatch*

In addition to undersized lake whitefish, 19 species were incidentally caught during the study period. Numerically, lake trout accounted for 82% of the incidental catch. Longnose sucker, walleye, burbot, round whitefish, and brown trout each composed 6.6, 2.8, 2.3, 1.3, and 1.0 % of the incidental catch respectively (Tables 10 and 11). The gill net fisher was permitted to retain walleyes but the trap net fisheries were not. Thus, all gill netted walleyes were recorded as dead. Eighty-five percent of trap netted walleyes were released alive and 15% were classified as dead or moribund on release.

The CPE of the combined incidental catch (principally lake trout) was similar for the two gear types in spring, but higher for trap nets in summer and for gill nets in fall (Table 11).

## Discussion

Our estimates of lake trout survival rates from largemesh gill net catches (39.6%) were relatively high but within the range of those reported by other investigators. Had we not adjusted for post-release mortality, our survival estimate would have been higher (55.7%). Gallinat et al. (1997) explored survival of lake trout bycatch from gill nets fished in Lake Superior. Of a total of 1,107 lake trout captured, 33% were thought to be in good enough condition to release. These survivors were transported to hatchery rearing tanks, where 28% of them died in the next 48 hours. Total survival, including during the recovery period, was 24%. As in our study, there were not pronounced seasonal differences in bycatch mortality. Toneys (2000) reported that 64% of lake trout taken in Wisconsin's Lake Michigan largemesh commercial gill net fishery were live at capture. Correcting for post-release mortality (as per Gallinat et al. 1997), gill net survival in the Wisconsin study was 54%. McNeil et al. (1988) found survival rates of trout and salmon caught in commercial gill nets were variable by species and generally low. 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). Compared to these latter studies, we experienced relatively high survival of lake trout; this may be partially due to differences in judgment on the part of onboard observers (Toneys 2000), but more likely because our gill nets were lifted by hand in a small boat. On our boat, the fish were removed and released immediately as the mesh came aboard, whereas mechanical gill net lifters may subject the catch to more physical stress than hand lifting. Therefore, the results of our study may not be directly applicable to larger gill net vessels using mechanical lifters.

In our study, 85% of the observed dead lake trout in trap nets were gilled or otherwise entangled in the pot or tunnel mesh and 15% were found dead, but not gilled or entangled, in the pot. Thus, entanglement appeared to be the leading cause of lake trout mortality in trap nets.

Our post-capture survival rates for trap netted lake trout were relatively low (83-92%, Table 7) because, unlike other studies, we deducted mortality associated with gilling in the mesh (28%, Gallinat et al. 1997) and for handling (1.6%, based on our laboratory observations of post-capture survival). Without these deductions, our survival estimate would have averaged 93.3%. Nontarget catches in trap nets in a Lake Superior study consisted mainly of lake trout and sublegal lake whitefish (Schorfhaar and Peck 1993). The lake trout incidental catch averaged 7.19 fish per lift, of which 96.3% survived. Lake trout bycatch survival in trap nets ranged from 97% to 94% in a central Lake Michigan study (Smith 1988). The catch rate of lake trout in the Lake Michigan study was higher than in our study and was much higher than for the Lake Superior study, averaging 75 per net lift in 1985 and 1986, frequently exceeding the catch of whitefish. The number of lake trout killed in the Lake Michigan study ranged from 2.3 to 5.2 per lift. Soak time (i.e., 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 differences in lake trout survival estimates of the Lake Superior and Lake Michigan studies (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, survival of lake trout averaged only 98.5% (Schneeberger et al. 1982). Peeters (2001) reported less than 0.2 lake trout killed per trap net lift in Wisconsin waters of Lake Michigan, where lake trout stocking rates are lower than in our study area. Lake trout stocking strategies, survival rates, abundance, and habitat quality vary widely among lake areas, which likely contributed to differing lake trout catch rates reported in the various Great Lakes studies.

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 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. The high recapture rates of pikeperch appear consistent with our laboratory observation that almost all lake trout taken live from trap net pots survived the experience. Trap netted lake trout in our study were transported over both water and land to the laboratory for post-capture observation. Thus, even though only 1.6% of the fish died, transportation and handling may have caused overestimation of post-capture mortality of trap netted lake trout.

Lake whitefish catch rates were highest and lake trout bycatch was lowest in fall for both gear types. The southern reaches of the study area attract large numbers of spawning-stage lake whitefish in fall, and indeed most lake whitefish captured there during fall were in spawning condition and were taken adjacent to shoals suitable for spawning. However, the same general area has been described as suitable for spawning by lake trout (Nester and Poe 1984; Eshenroder et al. 1995; Johnson and VanAmberg 1995). Peak lake trout spawning appears to be near 25 October in this area of Lake Huron, and lake whitefish peak spawning is during November (Michigan Department of Natural Resources, Alpena Great Lakes Fisheries Station, unpublished data); thus, a higher lake trout bycatch might have been expected for the fall period. Although lake trout were relatively abundant in the study area, the number of mature lake trout was low, principally because of high sea lamprey-induced mortality rates (Eshenroder et al. 1995; Johnson et al., in press). Therefore, lake trout bycatch could become more problematic in October and early November should sea lamprey numbers decline and the lake trout spawning stock experience recovery. Alternatively, low lake trout catch rates might also be expected in fall if restored lake trout prove to spawn, or stage prior to spawning, in different depths than those targeted by fishing.

The number of lake trout killed per lift was highest in spring with gill nets and in summer with trap nets. Lake whitefish catch rates were lowest in summer, but lake trout catch rates remained relatively high; thus the lake trout catch, as a percentage of lake whitefish harvest, was highest in both gear types in summer (Tables 7 and 9). Fortunately, because of higher target (lake whitefish) catch rates other times of year, the majority of Great Lakes commercial gill net fishery effort tends to be deployed in spring and fall.

Our gill net catch rates of lake trout might have been higher had there not been lake trout catch rate limits imposed on the gill net fishery. The commercial fisher was required to cease fishing a unit if the lake trout CPE significantly exceeded the limit; other gill net fisheries in Lake Huron were not so constrained. Furthermore, the presence of an onboard monitor may have changed the behavior of both the trap net and gill net operators with respect to their handling methods for the lake trout bycatch, which may have influenced gear-induced mortality estimates.

Other investigators reported higher incidence of sublegal lake whitefish in trap nets (Van Oosten et al. 1946; Schneeberger et al. 1982; Smith 1988; Schorfhaar and Peck 1993) than we observed. Lake whitefish monitoring data from the study area suggest there was a series of weak year classes prior to our study

(Michigan Department of Natural Resources, Alpena Fisheries Station, unpublished data).

### *Management Implications*

These study results should be helpful to managers who are attempting to rehabilitate lake trout while providing for treaty fishing rights for native Americans subject to the Treaty of 1836. Our study results suggest several ways to reduce lake trout bycatch mortality while accommodating lake whitefish harvest opportunities. One strategy would be to limit commercial whitefish harvest to trap nets. In fact, parties to the year 2000 Consent Decree pertaining to fishing in 1836 Treaty Waters elected to restrict commercial gear to trap nets for the entire study area. Another strategy would be to reduce effort or harvest in summer, when the ratio of lake trout killed per whitefish harvested was highest in both gear types.

Both gill net and trap net fisheries are capable of producing biologically excessive lake trout bycatch mortality. For example, a 100,000 kg commercial gill net fishery for whitefish with a seasonal distribution of catch and bycatch identical to our study gill nets, would kill nearly 10,150 kg of lake trout bycatch, which equaled the 2002 estimated surplus production of lake trout available for harvest in the study area (Shawn Sitar, Michigan Department of Natural Resources, unpublished data). The two trap net fisheries in this study harvested an average of 345,000 kg of lake whitefish annually from 1995-99. Applying our seasonal lake trout bycatch-whitefish ratios to the seasonal whitefish harvest, this level of whitefish harvest has caused an estimated lake trout kill of 4,900 kg annually, or nearly half the 2002 lake trout harvestable surplus, in the study area. In both the gill net and trap net fisheries, less than 10% of the lake whitefish catch was in the summer period, but 42% and 66% of the lake trout kill in gill nets and trap nets, respectively, was during summer. Thus, elimination of fishing during July, August, and September would have reduced the lake trout kill in trap nets by 3,200 kg annually at a cost of less than 10% of annual lake whitefish harvest.

Bycatch estimates are used for inputs to lake trout harvest allocation models and catch at age models for Lake Huron (Sitar et al. 1999; Woldt et al., in press). The Lake Huron lake trout fishery is the subject of recovery efforts. Because of changing rehabilitation strategies and stochastic variation associated with these fisheries, neither lake whitefish nor lake trout numbers are likely to remain static (Ebener 1997; Ebener et al., in press). Thus, the determination of lake whitefish available for harvest and levels of acceptable lake trout bycatch will require accurate, continuous accounting of target and nontarget fishing-induced mortality (Alverson and Hughes 1996; Chopin et al. 1996; Perret et al. 1996; Johnson et al. 2004).

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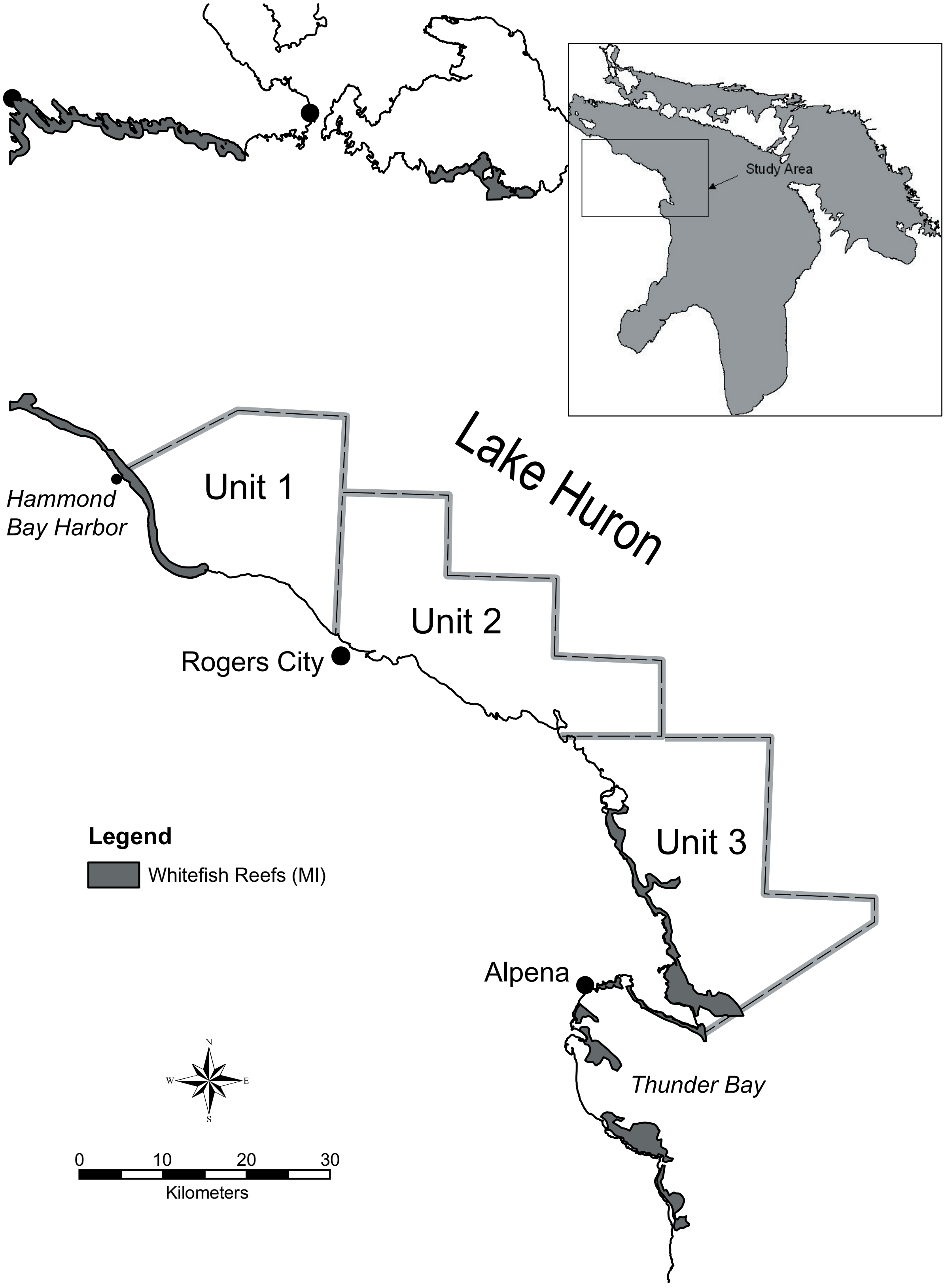

Figure 1.–Study area and whitefish spawning reefs, north-central Lake Huron.

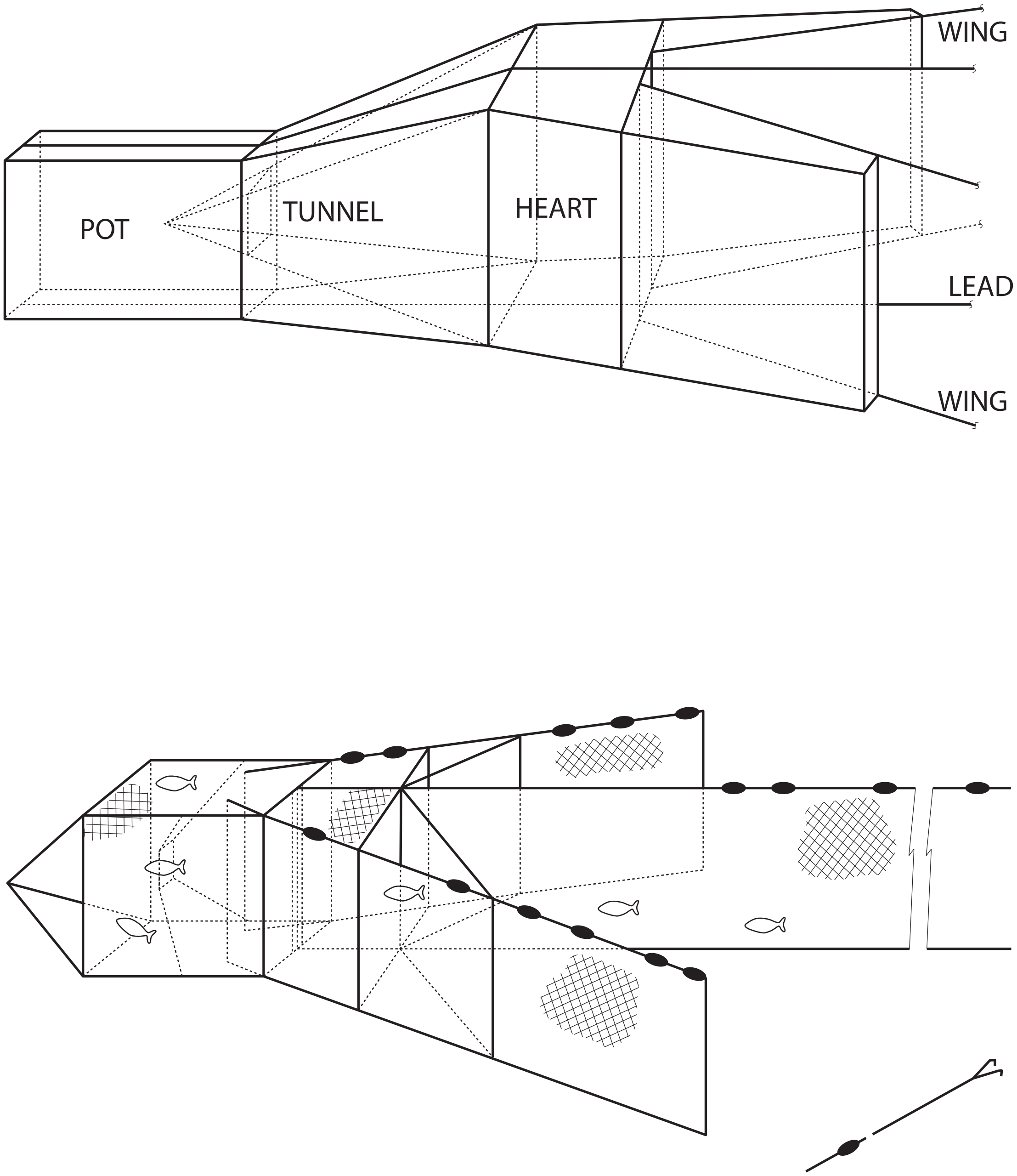

Figure 2.–Two types of Great Lakes trap nets.

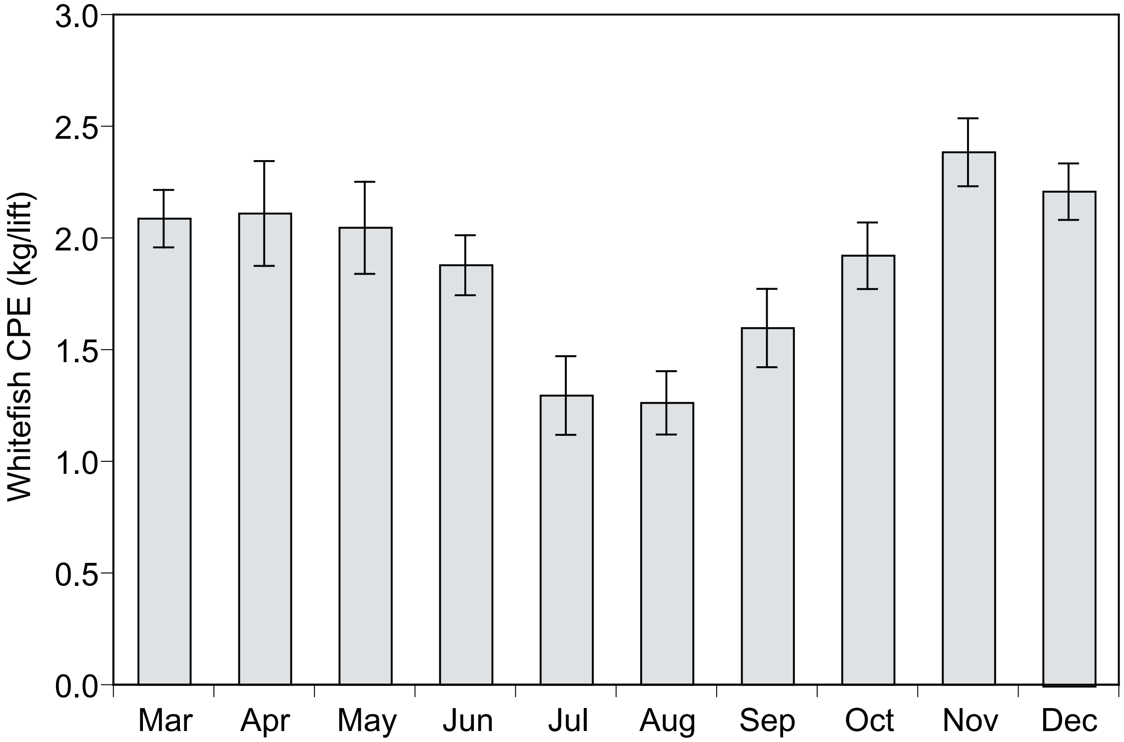

Figure 3.–Mean monthly $\log_{10}$ lake whitefish CPE (kg) in gill nets with 95% confidence limits, without seasonal partitioning in northern Lake Huron.

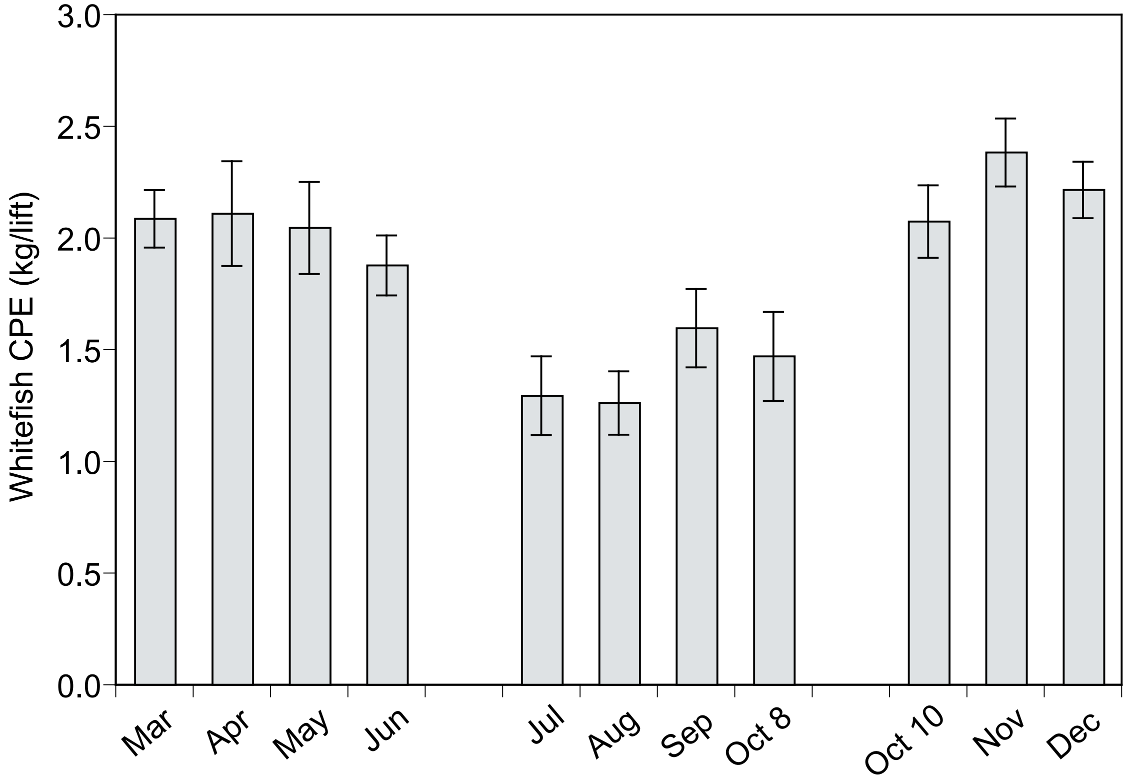

Figure 4.–Mean monthly $\log_{10}$ lake whitefish CPE (kg) in gill nets with 95% confidence limits, with seasonal partitioning in northern Lake Huron.

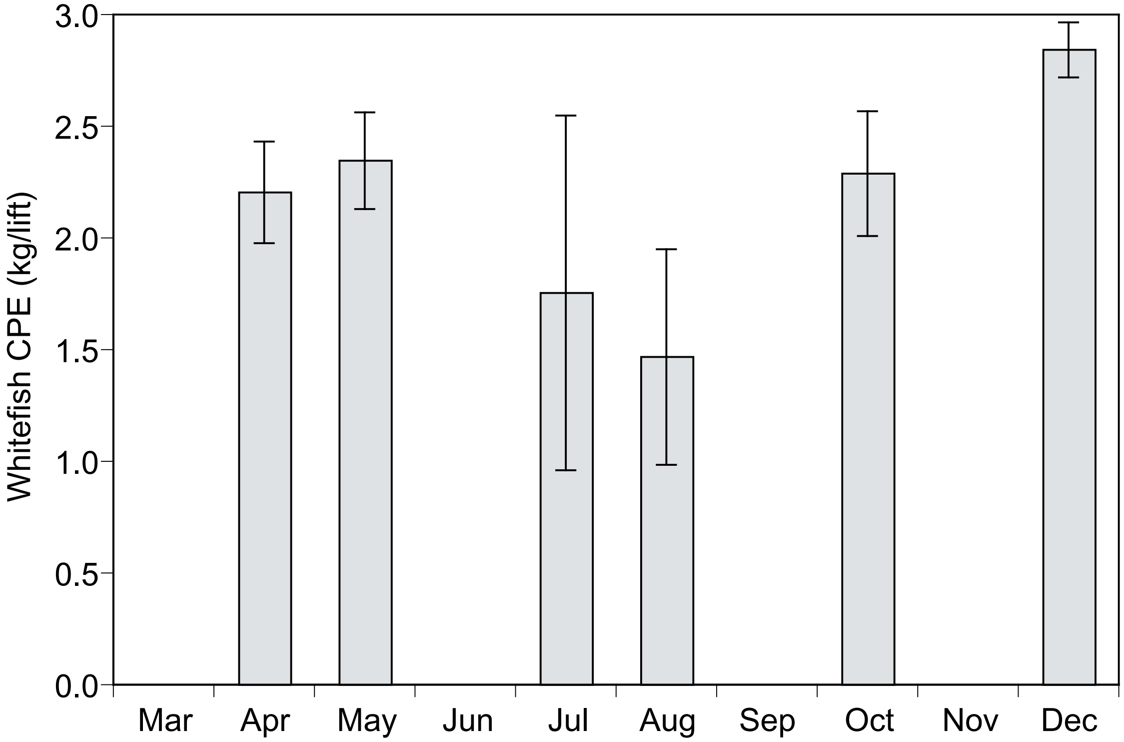

Figure 5.–Mean monthly $\log_{10}$ lake whitefish CPE (kg) in trap nets with 95% confidence limits, without seasonal partitioning in northern Lake Huron.

Table 1.–Names of species referenced.

| Common name | Scientific name |
|---|---|
| Alewife | *Alosa pseudoharengus* |
| Bloater chub | *Coregonus hoyi* |
| Brown trout | *Salmo trutta* |
| Burbot | *Lota lota* |
| Channel catfish | *Ictalurus punctatus* |
| Chinook salmon | *Oncorhynchus tshawytscha* |
| Coho salmon | *Oncorhynchus kisutch* |
| Common carp | *Cyprinus carpio* |
| Freshwater drum | *Aplodinotus grunniens* |
| Gizzard shad | *Dorosoma cepedianum* |
| Lake herring | *Coregonus artedi* |
| Lake sturgeon | *Acipenser fulvescens* |
| Lake trout | *Salvelinus namaycush* |
| Lake whitefish | *Coregonus clupeaformis* |
| Longnose sucker | *Catostomus catostomus* |
| Pikeperch | *Stizostedion lucioperca* |
| Rainbow smelt | *Osmerus mordax* |
| Rainbow trout | *Oncorhyhus mykiss* |
| Round whitefish | *Prosopium cylindraceum* |
| Sea lamprey | *Petromyzon marinus* |
| Smallmouth bass | *Micropterus dolomieu* |
| Walleye | *Sander vitreus* |
| White sucker | *Catostomus commersoni* |
| Yellow perch | *Perca flavescens* |
| Zebra mussel | *Dreissena polymorpha* |

Table 2.–Number of days of onboard monitoring by month, two gear types, north-central Lake Huron, October 1998-December 1999.

| | Month | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Gear type | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Total lifts |
| Gill nets | 10 | 15 | 21 | 20 | 30 | 31 | 26 | 54 | 26 | 27 | 260 |
| Trap nets | 0 | 11 | 12 | 0 | 4 | 5 | 0 | 44 | 0 | 20 | 96 |

Table 3.–Catches and catch per effort (CPE expressed as numbers) of lake whitefish and lake trout in gill nets and trap nets, by season, northern Lake Huron, 1998-99.

| Season and gear | | Total number observed whitefish harvested | Whitefish CPE | Whitefish CPE 95% CI (geometric mean) Lower | Upper | Total number observed lake trout caught | Lake trout CPE | Lake trout CPE 95% CI (geometric mean) Lower | Upper |
|---|---|---|---|---|---|---|---|---|---|
| Spring | | | | | | | | | |
| Gill nets | 66 | 7,286 | 110 | 90 | 136 | 1,960 | 29.7 | 23.13 | 38.13 |
| Trap nets | 23 | 4,384 | 191 | 136 | 268 | 704 | 30.6 | 17.17 | 54.52 |
| Summer | | | | | | | | | |
| Gill nets | 100 | 2,656 | 26 | 21 | 33 | 1,183 | 11.8 | 9.63 | 14.46 |
| Trap nets | 21 | 1,184 | 56 | 25 | 129 | 655 | 34.2 | 16.81 | 57.91 |
| Fall | | | | | | | | | |
| Gill nets | 94 | 17,142 | 183 | 148 | 226 | 756 | 8.0 | 6.34 | 10.10 |
| Trap nets | 52 | 34,672 | 667 | 510 | 900 | 48 | 0.9 | 0.77 | 1.05 |

Table 4.–Stage of maturity of lake trout catch by sampling period and area, north-central Lake Huron, fall, 1998 and 1999.

| | Maturity | | | Stage of maturity | | | |
|---|---|---|---|---|---|---|---|
| Period | Immature (%) | Mature (%) | Sample Size | Green | Ripe | Spent | Sample Size |
| Spring | 26.7 | 73.3 | 101 | 100.0 | 0.0 | 0.0 | 42 |
| Summer | 37.3 | 62.7 | 67 | 100.0 | 0.0 | 0.0 | 45 |
| Fall | 21.4 | 78.6 | 295 | 21.3 | 34.8 | 44.0 | 207 |

Table 5.–Mean depths (m, X ± 95% confidence interval) fished by commercial gill nets and trap nets in north-central Lake Huron during three seasons from October 1998-December 1999.

| | Season[a] | | |
|---|---|---|---|
| Gear type | Spring | Summer | Fall |
| Gill nets | 35.6±3.05 | 36.6±2.34 | 13.7±2.55 |
| Trap nets | 24.9±1.90 | 19.8±3.34 | 10.1±0.52 |

[a] For each gear type, similar means (P<0.01, ANOVA and Sheffe post-hoc analysis of differences) are underscored.

Table 6.–Lake trout catch and number killed per lift in monitored commercial trap net and gill net lifts, northern Lake Huron, 1998 and 1999.

| Season and gear | Effort (lifts) | Lake trout catch (no.) | Estimated no. lake trout killed[a] | No. lake trout killed per lift | No. lake trout killed per lift 95% CI (geometric mean) | | Kg of lake trout killed per lift | Kg of lake trout killed per lift 95% CI (geometric mean) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower | Upper | | Lower | Upper |
| Spring | | | | | | | | | |
| Gill nets | 66 | 1,960 | 1,137.0 | 17.23 | 13.647 | 21.753 | 21.1 | 16.0 | 27.8 |
| Trap nets | 23 | 704 | 57.2 | 2.48 | 1.699 | 3.620 | 2.5 | 1.5 | 4.2 |
| Summer | | | | | | | | | |
| Gill nets | 100 | 1,183 | 737.3 | 7.37 | 6.109 | 8.891 | 10.4 | 8.2 | 13.1 |
| Trap nets | 21 | 655 | 77.4 | 3.69 | 2.342 | 5.814 | 4.6 | 2.4 | 8.9 |
| Fall | | | | | | | | | |
| Gill nets | 94 | 756 | 460.1 | 4.89 | 3.986 | 6.000 | 7.8 | 5.8 | 10.4 |
| Trap nets | 52 | 48 | 8.2 | 0.16 | 0.149 | 0.172 | 0.2 | 0.1 | 0.3 |

[a] Number lake trout killed = number dead in net + 0.284 × number entangled in mesh but released live, both trap nets and gill nets + 0.016 × live lake trout in pot for trap nets.

Table 7.–Lake trout catch and kill as proportions of whitefish catch, by season and gear type, north central Lake Huron, 1998-99.

| | | | Catch summaries from numbers of fish | | | | Lake trout killed | |
|---|---|---|---|---|---|---|---|---|
| Season and gear | Observed effort (lifts) | Legal whitefish | Gear-induced lake trout mortality (%)[a] | Lake trout catch as percent of whitefish harvest[b] | Lake trout killed as percent of whitefish harvest[c] | Kg whitefish harvest | per kg whitefish | per 100,000 kg whitefish |
| Spring | | | | | | | | |
| Gill nets | 66 | 6,889 | 58.0 | 0.285 | 0.165 | 9,273 | 0.123 | 12,261 |
| Trap nets | 23 | 4,145 | 8.1 | 0.170 | 0.014 | 5,580 | 0.010 | 1,022 |
| Summer | | | | | | | | |
| Gill nets | 100 | 2,511 | 62.3 | 0.471 | 0.294 | 3,380 | 0.218 | 21,805 |
| Trap nets | 21 | 1,120 | 11.8 | 0.585 | 0.069 | 1,507 | 0.051 | 5,109 |
| Fall | | | | | | | | |
| Gill nets | 94 | 16,515 | 60.8 | 0.046 | 0.028 | 21,816 | 0.021 | 2,109 |
| Trap nets | 52 | 33,403 | 16.7 | 0.001 | 0.000 | 44,125 | 0.000 | 18 |

[a] Number lake trout killed = number dead in net + 0.284 × number entangled in mesh but released live, both trap nets and gill nets + 0.016 × live lake trout in pot for trap nets.

[b] Lake trout per lake whitefish = seasonal total number lake trout/number legal-sized whitefish during same period.

[c] Lake trout per lake whitefish = seasonal total number lake trout killed/number legal sized whitefish during same period.

Table 8.–Composition of observed catch by gear type and season, north central Lake Huron, 1998-99.

| Season and gear | Number |  |  | Percent |  |  |
|---|---|---|---|---|---|---|
|  | Legal-sized whitefish | Lake trout | Other species | Legal-sized whitefish | Lake trout | Other species |
| Spring |  |  |  |  |  |  |
| Gill nets | 7,286 | 1,960 | 9 | 78.7 | 21.2 | 0.1 |
| Trap nets | 4,145 | 704 | 17 | 85.2 | 14.5 | 0.3 |
| Summer |  |  |  |  |  |  |
| Gill nets | 2,539 | 1,183 | 194 | 64.8 | 30.2 | 5.0 |
| Trap nets | 1,120 | 655 | 194 | 56.9 | 33.3 | 9.9 |
| Fall |  |  |  |  |  |  |
| Gill nets | 16,493 | 756 | 548 | 92.7 | 4.2 | 3.1 |
| Trap nets | 33,402 | 48 | 177 | 99.3 | 0.1 | 0.5 |
| Totals |  |  |  |  |  |  |
| Gill nets | 26,318 | 3,899 | 751 | 85.0 | 12.6 | 2.4 |
| Trap nets | 38,667 | 1,407 | 388 | 95.6 | 3.5 | 1.0 |

Table 9.–Ratio of the average number of lake trout to the average number of lake whitefish captured by season and gear type in north-central Lake Huron, 1998-99.

| | | | Ratio per lift[b] | |
|---|---|---|---|---|
| Season[a] | Gear type | Number lifts monitored | Lake trout per whitefish[c] | Lake trout killed per whitefish[c] |
| Spring | Gill net | 66 | 0.5007 | 0.2731 |
| | Trap net | 23 | 0.2524 | 0.0241 |
| Summer | Gill net | 100 | 0.7652 | 0.4768 |
| | Trap net | 21 | 1.5570 | 0.1467 |
| Fall | Gill net | 94 | 0.1239 | 0.0692 |
| | Trap net | 52 | 0.0019 | 0.0003 |

[a] Spring = March – June, Summer = July-October 8, Fall = October 9- December.

[b] Means of number of lake trout per (whitefish+1) per lift.

[c] Lake trout:whitefish ratios for trap nets and gill nets differed significantly in all three seasons (Mann-Whitney U, $P \leq 0.04$).

Table 10.–Number by species of all bycatch observed by gear type and season, north-central Lake Huron, 1998-99.

| | Period | | | | | |
|---|---|---|---|---|---|---|
| | Spring | | Summer | | Fall | |
| Species | Gill nets | Trap nets | Gill nets | Trap nets | Gill nets | Trap nets |
| Lake trout released live[a] | 823 | 657 | 446 | 587 | 296 | 40 |
| Lake trout dead[a] | 1,137 | 57 | 737 | 77 | 460 | 8 |
| Sublegal lake whitefish | 1 | 79 | 1 | 21 | 0 | 0 |
| Chinook salmon released | 0 | 0 | 0 | 0 | 0 | 0 |
| Chinook salmon dead | 0 | 0 | 2 | 4 | 9 | 0 |
| Coho salmon released | 0 | 0 | 0 | 0 | 0 | 0 |
| Coho salmon dead | 1 | 0 | 14 | 0 | 2 | 0 |
| Walleye released | 0 | 0 | 0 | 49 | 0 | 15 |
| Walleye dead | 0 | 0 | 9 | 6 | 101 | 5 |
| Burbot | 7 | 16 | 68 | 4 | 40 | 15 |
| Brown trout released | 0 | 0 | 0 | 0 | 0 | 0 |
| Brown trout dead | 0 | 0 | 5 | 0 | 62 | 0 |
| Rainbow trout released | 0 | 0 | 0 | 1 | 2 | 0 |
| Rainbow trout dead | 0 | 0 | 0 | 0 | 0 | 0 |
| Round whitefish | 0 | 0 | 4 | 5 | 72 | 5 |
| Channel catfish | 0 | 0 | 6 | 25 | 6 | 18 |
| Longnose sucker | 0 | 0 | 53 | 38 | 221 | 110 |
| White sucker | 0 | 0 | 8 | 0 | 0 | 3 |
| Carp | 0 | 0 | 10 | 0 | 1 | 3 |
| Freshwater drum | 0 | 0 | 0 | 49 | 0 | 2 |
| Lake herring | 0 | 1 | 0 | 0 | 1 | 0 |
| Lake sturgeon | 0 | 0 | 0 | 1 | 0 | 0 |
| Bloater chub | 0 | 0 | 15 | 0 | 27 | 0 |
| Smallmouth bass | 0 | 0 | 0 | 0 | 2 | 0 |
| Yellow perch | 1 | 0 | 0 | 0 | 2 | 0 |
| All incidental catch: | 1,970 | 810 | 1,378 | 867 | 1,304 | 224 |

[a] Corrected for gear-induced mortality

Table 11.–Catch/lift by species of all observed bycatch by gear type and season, north-central Lake Huron, 1998-99.

| | Period | | | | | |
|---|---|---|---|---|---|---|
| | Spring | | Summer | | Fall | |
| Species | Gill nets | Trap nets | Gill nets | Trap nets | Gill nets | Trap nets |
| Lake trout released live[a] | 12.47 | 28.57 | 4.46 | 27.95 | 3.15 | 0.77 |
| Lake trout dead[a] | 17.23 | 2.48 | 7.37 | 3.67 | 4.89 | 0.15 |
| Sublegal lake whitefish | 0.02 | 3.43 | 0.01 | 1.00 | 0.00 | 0.00 |
| Chinook salmon released | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chinook salmon dead | 0.00 | 0.00 | 0.02 | 0.19 | 0.10 | 0.00 |
| Coho salmon released | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Coho salmon dead | 0.02 | 0.00 | 0.14 | 0.00 | 0.02 | 0.00 |
| Walleye released | 0.00 | 0.00 | 0.00 | 2.33 | 0.00 | 0.29 |
| Walleye dead | 0.00 | 0.00 | 0.09 | 0.29 | 1.07 | 0.10 |
| Burbot | 0.11 | 0.70 | 0.68 | 0.19 | 0.43 | 0.29 |
| Brown trout released | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Brown trout dead | 0.00 | 0.00 | 0.05 | 0.00 | 0.66 | 0.00 |
| Rainbow trout released | 0.00 | 0.00 | 0.00 | 0.05 | 0.02 | 0.00 |
| Rainbow trout dead | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Round whitefish | 0.00 | 0.00 | 0.04 | 0.24 | 0.77 | 0.10 |
| Channel catfish | 0.00 | 0.00 | 0.06 | 1.19 | 0.06 | 0.35 |
| Longnose sucker | 0.00 | 0.00 | 0.53 | 1.81 | 2.35 | 2.12 |
| White sucker | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.06 |
| Carp | 0.00 | 0.00 | 0.10 | 0.00 | 0.01 | 0.06 |
| Freshwater drum | 0.00 | 0.00 | 0.00 | 2.33 | 0.00 | 0.04 |
| Lake herring | 0.00 | 0.04 | 0.00 | 0.00 | 0.01 | 0.00 |
| Lake sturgeon | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 |
| Bloater chub | 0.00 | 0.00 | 0.15 | 0.00 | 0.29 | 0.00 |
| Smallmouth bass | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 |
| Yellow perch | 0.02 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 |
| All incidental catch: | 29.85 | 35.22 | 13.78 | 41.29 | 13.87 | 4.31 |

[a] Corrected for gear-induced mortality

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