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Comparison of the Performance in Recreational Fisheries of Brown Trout Stocked as Spring and Fall Yearlings, Lake Huron

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Abstract.–We compared recreational harvest of put-grow-take brown trout stocked as yearlings during either late spring (June) or fall (October) at two sites, Thunder Bay and Tawas Bay, in Lake Huron, 2001–2003. An objective of the study was to determine whether performance was better for fish stocked at one time of year or the other, with the ultimate hope that this information could be used to reverse sharp declines documented for the Lake Huron brown trout fishery since 1996. In Thunder Bay, fall yearlings produced 2.3 times more observed returns to creel than spring yearlings, but returns there were nearly equal for the two stocking strategies when based upon unit of weight stocked. The pattern of returns in Tawas Bay was almost the reverse, with spring yearlings producing 3.9 times as many returns to creel as fall yearlings and 4.3 times the returns based on unit of weight stocked. There were no pronounced differences in growth between the spring and fall test groups. Brown trout had been stocked in June during 1991–2000 because the abundance of spawning alewives nearshore at that time of year was thought to provide a buffer from predators for the young brown trout. Alewives were declining in Lake Huron during this study, however, and by 2003 they were nearly absent. Predator fish, the most common of which were walleyes, fed mostly on alewives until the alewife decline. During this study the high percentage of void walleye stomachs (90%) suggested prey was in relatively short supply. Avian predators were also abundant for years previous to and during this study. In particular, double-crested cormorant numbers rose exponentially from 1989 to 2005 in Thunder Bay. We speculate that lower availability of alewives and other prey may have resulted in avian and fish predators consuming more than the usual number of stocked brown trout during the course of our study. Predation may have been especially high during spring when piscivorous birds were nesting and post-spawning walleyes were experiencing warming temperatures and

consequent rising energy demands. Differences in cormorant and alewife numbers between the two study sites may have been the reason for the higher return rates of spring yearlings in Tawas Bay than Thunder Bay. Soon after data collection for this study was concluded, emerald shiners began appearing in the nearshore, particularly in harbors and river mouths, in exceptionally high numbers during October. The shiners remained nearshore until early spring. Brown trout are distributed closer to shore than most other salmonids and therefore emerald shiners would be available as prey for fall-stocked yearlings during winter. Cormorant management began in Thunder Bay in 2006 and by 2007 the number of nesting pairs was less than half the number present during our study. If alewives remain scarce and emerald shiner abundance persists, conditions may now favor survival of yearling brown trout stocked during October over those stocked in spring.

Introduction

Lakes Huron and Michigan host what are perhaps the world's largest put-grow-take salmonine recreational fisheries (Whelan and Johnson 2004). Supplementation of salmonine stocks with hatchery fish has been necessary because of widespread recruitment failures of species such as lake trout, brown trout, rainbow trout, Chinook salmon, and coho salmon (see Table 1 for scientific names of fish). Natural recruitment failures were due to insufficient parental stock abundance or low survival of young caused by a combination of factors such as sea lamprey depredations on native predator stocks, the overpopulation of invasive alewives, other invasive species, overharvest of native predator stocks, physical habitat loss, and water quality degradation (Smith 1968; Coble et al. 1990; Eshenroder et al. 1992; Whelan and Johnson 2004). The 1960s and 1970s saw rehabilitation programs begin throughout the Great Lakes that included water quality initiatives, commercial fishing restrictions, intensive sea lamprey control, fishway construction, and extensive stocking of the system with coho and Chinook salmon, and rainbow, lake and brown trout (Tody and Tanner 1966; Kocik and Jones 1999; Whelan and Johnson 2004). These changes led to more ecologically balanced fish communities, recreational and commercial fisheries valued in excess of $2 billion to Michigan's economy annually, and restoration of self-sustaining lake trout in Lake Superior (Kocik and Jones 1999; Whelan and Johnson 2004). However, the salmonine fisheries of lakes Huron and Michigan remained principally supported by stocking. Self-sustaining naturalized populations of most introduced salmonine species have failed to develop. Where naturalized populations have developed, most stocks remain recruitment limited (Keller et al. 1990; Whelan and Johnson 2004). In the case of brown trout in the Great Lakes, self-sustaining reproduction is limited to a few isolated populations. Thus, many of the salmonine fisheries of lakes Michigan and Huron, including the one for brown trout in particular, are dependent on put-grow-take stocking programs (Whelan and Johnson 2004).

Brown trout have been an important element of the recreational fishery of Lake Huron since at least 1972 (Weber 1988; Johnson and Rakoczy 2004). From 1972 through 1986, brown trout recreational harvest in Thunder Bay, Lake Huron was loosely a function of stocking ($R^2 = 0.27$: estimated harvest as dependant variable regressed on the number of yearling brown trout stocked one year prior to harvest). Return to creel was about 10% of number stocked during the early 1970s (Weber 1988). After 1986, however, the relationship between stocking and harvest weakened (R^2 declining to 0.17). Recreational catch rates for brown trout were low in certain years, particularly 1979–84, 1990–91, and 1997–2005 (Table 2).

Brown trout typically have been stocked during June, when abundance of spawning alewives at stocking sites is highest. It was presumed that alewives, when abundant, provided a prey base for predators, thereby buffering predation on recently stocked trout. Since 1995, however, alewife numbers declined and predator numbers, particularly double-crested cormorants *Phalacrocorax auritus,* increased sharply in Thunder Bay. The 1997–2005 decline of brown trout catch rates in

Thunder Bay was attributed by Johnson and Rakoczy (2004) to increasing predation on recently stocked fish. Survival of stocked brown trout appeared to be proportional to adult alewife abundance and inversely correlated with numbers of nesting double-crested cormorants. Not only does a June stocking date correspond with the nesting period when cormorant consumption is highest, it is also near the time of peak feeding rates of walleyes, another important predator on brown trout in Thunder Bay. During the 1990s, walleyes composed 53% of fish longer than 400 mm in total length taken in assessment nets in Thunder Bay. Alewives dominated the diets of these walleyes but brown trout were regularly seen in the stomachs of walleyes after stocking events (Johnson and Rakoczy 2004).

A plan to try stocking brown trout in Lake Huron during October was predicated on the assumption that there would be reduced predation on stocked fish by double-crested cormorants and walleyes in the fall. Predation effects of double-crested cormorants should be lower because they migrate from Thunder Bay each September and few if any remain by the first week of October. Walleye predation should also be reduced in fall due to a seasonal decline in their metabolic rate and the larger size of fall yearlings (Yule et al. 2000).

The objectives of this study were to determine whether yearling brown trout stocked in fall contributed more to recreational fishing in Lake Huron than those stocked during spring and whether there were differences in size at age between spring- and fall-stocked yearlings when they returned to the creel. Spring yearling brown trout were stocked in June whereas fall yearlings were held in hatcheries four more months and released in early October.

Study Sites

Two study sites were selected based on their stocking histories. Thunder Bay, Lake Huron, is located on the northeast part of Michigan's Lower Peninsula; Tawas Bay is 60 miles south of Thunder Bay and makes up the north shore of outer Saginaw Bay (Figure 1). Thunder Bay measures approximately 22,000 ha and has a maximum depth of 27 m. Tawas Bay measures approximately 6,500 ha and has a maximum depth of 12 m. In both bays midsummer water temperatures often exceed those suitable for salmonids and there is nothing to restrict brown trout from moving to the deeper, colder main basin waters of Lake Huron. Thunder Bay was selected for study because it was historically one of two major stocking sites for brown trout in Lake Huron and it is where prior research has been done (Johnson and Rakoczy 2004). Tawas Bay was chosen for the second study site because it is the other major center of brown trout stocking in Lake Huron and has produced a brown trout fishery at least as important as that of Thunder Bay (Table 2).

Methods

Two test groups of yearling brown trout were stocked at each study site annually from 2001 through 2003; spring-yearlings stocked from 9 to 19 June, and fall yearlings from 1 to 15 October. Spring yearlings were marked with left-ventral fin clips; fall yearlings with right-ventral clips. Approximately equal weights of each test group were stocked (Table 3) to simulate the limitation of fish production capacity that usually dictates stocking levels prescribed at each site by managers. We planned to stock half as many fall yearlings as spring yearlings each year because their individual average weight (177 gm) was 2.2 times that of spring yearlings (78 gm). All study fish were reared at Thompson Hatchery and all were the same strain (Seeforellen) of brown trout.

Harvest was estimated using expandable, stratified surveys of effort, catch rate, and catch composition of the recreational fishery at each major fishing port on Michigan waters of Lake Huron (Figure 1). Effort was measured using randomly scheduled instantaneous counts of shore anglers, pier anglers, and boat trailers at boat access sites at main basin ports, including Thunder Bay. At Tawas and Saginaw bays, boat effort was measured using aerial counts. Harvest was measured using completed trip interviews of angling parties. The counts and interviews were scheduled using a random, stratified design (Rakoczy and Svoboda 1994). Creel survey clerks were required to take biological data from all brown trout encountered at Thunder Bay and from a subsample of the observed catch at all other ports. Biological data collected from the recreational harvest included species, fin clip, length, weight, and scale samples for age determination at Thunder Bay; at Tawas Bay, all brown trout observed in the catch were inspected and lengths and fin clips were recorded. Ages were assigned to the Tawas Bay catch based upon lengths using data from Thunder Bay brown trout as a key. The creel survey was conducted from 1 May to 30 September at most ports on the main basin of Lake Huron and from 1 April to 31 October of each year at Thunder Bay and Tawas Bay. For Tawas Bay and other Saginaw Bay ports, a winter creel survey was also conducted when there was sufficient ice thickness to permit ice fishing.

The stocking site in Thunder Bay was near the mouth of the Thunder Bay River in Alpena (Figure 1). Johnson and Rakoczy (2004) showed that brown trout return to creel was positively correlated with adult alewife abundance at the stocking site in the year of stocking. For this reason, alewife numbers near the Thunder Bay stocking site were indexed from gill-net catches during May and June, 1990–2006 (except for 1996, 1997, and 1999 when the surveys were not conducted). Nets for these surveys were 1.8-m deep, 76-m long, and consisted of five 15-m panels of 38-, 51-, 64-, 89-, and 114-mm multifilament nylon mesh (stretch measure). Gill nets were set on the bottom across depth contours that were in the range of 1.5 to 7 m, which was the depth range of the majority of spawning-phase alewives. Catch from these same nets was used from 2000 through 2006 to assess abundance and examine diets of piscine predators in Thunder Bay. A unit of effort for both alewives and predator fish was defined as an overnight set of 1,000 meters of net. Catch was expressed as number of fish caught per unit of effort (CPUE). Fish caught were weighed and measured, scales or spines were taken from most predator species for age determination, sea lamprey wounds were classified, and stomachs of predator species were examined for diet. Prey items in each predator fish stomach were identified and counted.

The study plan originally called for sampling Thunder Bay with gill nets in October after the fall yearlings had been stocked. We set 762 m of the same gill nets used during spring in October 2001. Wild and hatchery-origin lake trout spawn in the vicinity of the Thunder Bay stocking site and it was decided not to sample in fall 2002–2003 due to risk of gill-net induced mortality on this spawning stock.

We tested the hypothesis that there were no differences between return to creel or size at age of brown trout stocked in spring and fall. Based on Johnson and Rakoczy's (2004) findings that 97% of marked brown trout stocked in Thunder Bay at Alpena were harvested within a 30-mile radius of Alpena (Rockport to Harrisville), we assumed all marked brown trout in this study north of, and including, Harrisville were from the Thunder Bay stocking site and those observed south of Harrisville were from the Tawas Bay stocking site (Figure 1). For each study site (Tawas and Thunder bays), performance of the spring- and fall-stocked yearlings was measured by comparing catch observed by survey clerks in the angler creel versus expected returns. Differences were compared using binomial tests comparing the expected with the actual return ratios using SPSS software (SPSS, Chicago IL). Expected values were the ratios of number or weight stocked during fall to the total of spring and fall test fish stocked each year. We used t tests to compare lengths and weights at age of fish sampled from the creel during the months of July and August. Tested differences showing the probability of the null hypotheses to be ≤ 0.05 were considered significant.

Results

By number, 34.5% of this study's yearling brown trout were stocked in fall; 65.5% were stocked in spring. By virtue of their greater size, however, slightly more (54.6%) biomass of brown trout was stocked in fall than in spring (Table 3). At both stocking sites returns from fish stocked in the third year of the study were lower than from years one and two (Table 4).

Numerically in Thunder Bay, 56.9% of study fish observed in the creel were stocked in the fall. Returns varied across years but averaged 2.3 times as many returns of fall-stocked fish per 50,000 stocked as spring-stocked fish (Table 4). The difference between fall-stocked to spring-stocked brown trout returns to the creel was higher than expected for the 2002 cohort ($p \leq 0.001$; n=61), but the difference was not significant for the 2001 ($p = 0.08$; $n = 32$) or the 2003 ($p = 0.34$; $n = 9$) cohorts. There was no significant difference ($p \geq 0.17$; n=102) in return to the creel of yearlings from the two stocking seasons based on weight of fish stocked for any year during the Thunder Bay study.

Unlike Thunder Bay, only 20.5% of study fish observed in the creel at Tawas Bay were from fall stocking. Spring-stocked yearlings produced 1.8 times the observed returns per number stocked as fall yearlings and 4.3 times more per unit of weight stocked. The differences were significant for the 2001 and 2002 cohorts in terms of both numbers and weight of each group stocked ($p < 0.002$; n=258). Returns to the creel were lower and nearly equal for the 2003 cohort (Table 4) and were not significantly different from those expected based on number or weight of each group stocked.

Creel survey clerks observed more study brown trout at Tawas than Alpena (Table 4). Averaged across study years and size groups, 2.2 times more brown trout were observed per 50,000 yearlings stocked at Tawas Bay than Thunder Bay. Angler hours showed a similar pattern, with Tawas Bay receiving 2.84 times more angler hours than Thunder Bay during the study period. Creel census was conducted during January-March at Tawas and 25% of the estimated harvest of test brown trout was during this period (24% of spring-stocked fish were observed during winter, n = 54; 29% of fall stocked were during winter, n = 17). Creel census was not conducted during January-March at Thunder Bay.

Creeled fall-stocked yearling brown trout from Thunder Bay were significantly larger than spring-stocked yearlings in weight ($p = 0.043$) but not in length ($p = 0.36$) at age 2 (Table 5). Paradoxically, spring yearlings were significantly longer ($p = 0.023$) and heavier ($p = 0.031$) at age 3 than fish stocked in fall (Table 5). There were only four observations of lengths or weights of age-4 fish stocked in Thunder Bay, so no meaningful comparison between spring- and fall-stocked fish was possible for that age group. Weights were not measured in the Tawas Bay area and there were no significant differences in lengths at capture for either age-2 or age-3 brown trout between those stocked in spring and fall (Table 6).

The CPUE of most predator and prey species in the spring gill-net assessment of Thunder Bay declined steadily from 2000 through 2006, led by a steep decline in alewives. Walleyes were the chief predator fish in the catch and the CPUE of walleyes was relatively stable, averaging 58.5 during 2000–2006 (Table 7) and 51.5 over the three-years of experimental stocking. Round gobies were the most prevalent prey fish in the predator fish diets during June. Only 18 alewives were seen in predators' stomachs during the three years of netting during experimental brown trout yearling stocking. Five brown trout were found in stomachs of walleyes (Table 8).

The alewife abundance index in Thunder Bay declined from 1993 through 1998, rebounded somewhat in 2000 and 2001, but declined again in 2002–2005. Catch per unit effort for alewives was near zero in 2005 and 2006 (Figure 2).

Unlike the spring assessment, which caught predominantly cool- and warm-water species, the fall survey was dominated by cold-water fishes. The majority of the fall 2001 gill-net catch from Thunder Bay was very recently stocked brown trout and other salmonids, including spawning-phase lake whitefish and lake trout. Seven walleyes were caught, for a catch rate of 2.8 per 1,000 m. Stomachs of most predators in the catch were void (Table 9). Among the 54 recently stocked fall-yearling brown trout caught, 69% had stomachs that were void and 28% had eaten Diptera larvae.

Discussion

Return differences were equivocal at Thunder Bay, with fall yearlings producing better returns when adjusted for number stocked, but neither fall nor spring yearlings producing better creel return rates per unit of weight stocked. At Tawas Bay, however, spring yearlings returned at considerably higher rates than fall yearlings with respect to both number and biomass of fish stocked. Considering the results from both ports together, stocking yearlings during spring was the more effective method during the first two years, but neither method was producing satisfactory returns by the third year.

The larger number of returns of study fish at Tawas Bay (2.2 times the returns at Thunder Bay) was principally a function of fishing effort. When adjusted for fishing effort, which was 2.84 times higher at Tawas Bay, the total number of returns at Tawas and Thunder bays was similar. Winter creel surveys were conducted at Tawas and not at Thunder Bay. The winter creel effort at Tawas contributed 25% of the test-fish observations there and thus also contributed to the higher estimated harvest of brown trout at Tawas. The percentage of each test group's harvest that occurred during the three winter months at Tawas was about the same. Thus the use of winter creel data at Tawas did not alter the return rates of one test group relative to the other.

In Thunder Bay, fish stocked as fall yearlings were on average 0.67 kg heavier at age 2 than fish stocked as spring yearlings. Inexplicably, fish stocked as spring yearlings were on average 0.86 kg heavier at age 3 than those stocked as fall yearlings. Both differences were significant. There was no detectable difference in length at age for spring- or fall-stocked brown trout at Tawas Bay, but this may be due to low sample sizes and the use of a length key for aging the Tawas Bay fish. Overall, no differences in size at age between the two test groups were enough to demonstrate a clear advantage for either group.

Alewives were the principal prey fish available in Lake Huron until 2003 (Bence et al. 2008) and alewives composed the majority of lake trout, brown trout, and walleye diets in the study area from 1990 to 1995, especially during late May and early June (Johnson and Rakoczy 2004; Johnson et al. 2007) when alewives congregated in nearshore waters to spawn. A brown trout "stocking window" was presented by this abundance of spawning-phase alewives (Johnson and Rakoczy 2004) because the alewives served as a buffer from predation on young brown trout. Therefore, brown trout during that period were routinely scheduled for stocking during early June.

In Thunder Bay, the gill-net CPUE for alewives was in sharp decline during the study. The 1990–2000 average CPUE was 724. In 2001, the first year of stocking for this study, the alewife CPUE was 551 and it declined to 182 and 105 in 2002 and 2003, respectively. Alewives nearly disappeared from bottom trawl assessment catches conducted by the Great Lakes Science Center in central and southern Lake Huron in 2003 (Bence et al. 2008). Thus alewives were relatively scarce and declining during the study years. During 2001–2003, round gobies contributed more than alewives to the diets of predator fish taken during the spring gill-net assessment of Thunder Bay (Table 8). Evidently, the inferred stocking 'window' afforded when there was a plentiful supply of spawning alewives was diminishing during the course of this study. Near absence of alewives may be the reason for the low return rates of the brown trout stocked in 2003, particularly at Thunder Bay. Although round gobies became abundant during the alewife decline, the bottom-oriented gobies were much smaller in size and may have been less vulnerable to predation than the pelagic alewife. Supposing that predators might have eaten high numbers of brown trout in the absence of alewives, the sharp decline in alewives would explain the concurrent decline in brown trout returns from the 2001–2003 stocking seasons.

Unfortunately, there was no index netting for alewives at Tawas Bay, so alewife abundance trends are less clear at this study site. If post-stocking survival of spring yearling brown trout was correlated with alewife abundance at Tawas Bay, as it has been shown to be at Thunder Bay (Johnson and Rakoczy 2004), the higher survival of spring yearlings at Tawas Bay relative to Thunder Bay would suggest alewife abundance was higher at Tawas Bay during the first two years of the study. In any case, the June 'stocking window' proposed by Johnson and Rakoczy (2004) is no longer a viable management strategy for the stocking of yearling brown trout in Lake Huron because alewives collapsed lake wide in 2003 (Bence et al. 2008). Similarly, stocking of Chinook salmon in Lake Huron has experienced a sharp decline in success, apparently also because of the collapse of alewives and rising post-stocking predation on the stocked salmon (Johnson et al. 2007).

Johnson and Rakoczy (2004) also presented circumstantial evidence that double-crested cormorant predation has contributed to declining post-stocking survival of spring-stocked brown trout yearlings in Thunder Bay. Cormorant numbers increased 8.4-fold there from 1989 to 1997. Their annual consumption of fish was near 1.2 million kg in 2005, which exceeded prey biomass estimates from bottom trawling of Thunder Bay (Johnson et al. 2008). When alewives are abundant, the chief component of the cormorant diet during late spring is alewives (Karwowski 1994; Ross and Johnson 1995; Maruca 1997; Johnson et al. 1999), but alewives were declining during the study period and were nearly absent by 2003. Large numbers of cormorants were observed feeding at brown trout stocking sites in June in Thunder Bay. Given the high consumption demands of the Thunder Bay colonies and the decline in alternative prey (alewives), cormorant predation may have significantly cropped the spring brown trout yearlings stocked in Thunder Bay. There are two cormorant rookeries on the Charity Islands near the Tawas Bay stocking site. Prey consumption of the Charity Island rookeries is estimated to be 0.55 million kg (D. Fielder, Alpena Fisheries Research Station, unpublished data), less than half that of the Thunder Bay area. The Charity Islands are 29 km from the Tawas Bay stocking site while the nearest rookery to the Thunder Bay stocking site was 1 km away. Thus, it is possible higher abundance and proximity of cormorants, combined with lower abundance of alewives as alternative prey for cormorants and other predators, caused lower survival and hence lower returns of brown trout stocked as spring yearlings at Thunder Bay.

All but a few cormorants had migrated out of the study sites by the fall stocking period in early October; thus, cormorant predation was not a factor in brown trout yearling survival during the period immediately following fall stocking. Walleye numbers were also much lower in fall; the gill-net CPUE for walleye in fall 2001 was only 15% of the average during the June survey. Evidently predator abundance was considerably lower in Thunder Bay in fall; however, prey for predators such as walleyes may have been low in abundance in October, as evidenced by the high incidence (90%) of void walleye stomachs (Table 9). The effect of diminished food supply was probably mitigated by declining predator metabolic rates; prey demands of walleyes and other predators were ebbing with declining temperatures in fall.

Availability of food for the stocked brown trout was also probably at a seasonal low point during fall, but so presumably were metabolic needs of these trout. Spring yearlings consume principally terrestrial insects during the first few months following stocking (Johnson and Rakoczy 2004). Seasonal availability of wind-blow terrestrial invertebrates could represent an important transitional food for hatchery fish, providing a readily available food source as the acclimating fish learn to capture less vulnerable types of prey, such as small fish. Terrestrial insects would have been scarce during the period after the October stocking dates. The majority (69%) of 54 fall-stocked yearling brown trout examined for diet data had void stomachs; the balance had eaten various numbers of Diptera larvae. Slow growth resulting from low food availability and cooling water temperatures could have extended the exposure period of fall-stocked yearlings to predation. A total of 18 fall stocked brown trout were measured between February and April the year after stocking and their mean length was only 298 mm. Some were as small as 254 mm. These fish were still small enough to be consumed by cormorants and the largest piscine predators 4–6 months after stocking. Stocking larger yearlings in fall may have lessened vulnerability to predation during the period immediately after stocking; nevertheless, the fall-stocked fish remained vulnerable, perhaps especially the following spring when cormorants returned to the area.

Our results at Thunder Bay were comparable with those of Yule et al. (2000) in eastern Wyoming, where returns of fall-stocked rainbow trout, were nearly twice those of spring-stocked trout. The trout stocked during fall in the Wyoming study were similar in size to our fall-stocked brown trout. Low survival of spring-stocked trout in the Wyoming study was attributed to predation of trout fingerlings by abundant post-spawning walleyes whose metabolic and prey consumption rates rose with increasing spring water temperatures. The better performance of spring- than fall-stocked yearlings at Tawas Bay suggests that spring predation losses in Tawas Bay during 2001–2002 were less than in Thunder Bay or the eastern Wyoming study. The relatively low return of spring yearlings stocked at Tawas Bay in 2003 suggests spring predation rates had risen.

In 2005 and 2006, emerald shiners became exceptionally abundant (Schaeffer et al. 2008), especially near shore in late fall through early spring (Alpena Fisheries Research Station unpublished observations). It is speculated, therefore, that growth rates of fall-yearling brown trout could be greater now than during the study period, with the current high abundance of emerald shiners potentially providing enhanced forage in fall and winter at the stocking sites.

Genetic work has shown that the Seeforellen brown trout strain has low levels of genetic diversity and this characteristic appears to have been exacerbated by successive generations of breeding in hatcheries among relatively few adults (K. Scribner, Michigan State University, personal communication). The strain appears to be unusually vulnerable to cold-water and gill diseases as well as abnormalities, including vertical orientation in raceways when at rest, and bilateral asymmetry (with respect to gill raker, gill arch, and pectoral fin ray counts) (E. Eisch, Oden State Fish Hatchery, Michigan Department of Natural Resources, personal communication). These observations are consistent with genetically-based effects that could persist after the fish are released to the wild. Seeforellen strain is principally used for stocking the Great Lakes, thus the low genetic diversity of this strain may be contributing to declining success of brown trout stocked in Lake Huron. By using only one strain of brown trout, however, we controlled for any effect of strain selection on performance in this study.

Management Implications

Lake Huron was in a state of rapid change during this study period (Bence et al. 2008). Alewives were declining, perhaps at a greater rate in Thunder Bay than Tawas Bay. Predators were switching to other prey species and taking a larger share of stocked salmonids than usual (Johnson et al. 2007). Alternative prey species were not yet rebounding in response to the loss of alewives (Bence et al. 2008). Double-crested cormorants remained at near record high numbers in Thunder Bay. Metabolic rates of predator fish rise in spring with warming water temperatures and consumption demands of piscivorous birds peak in June as their nesting season begins. These factors together probably caused increased predation on stocked brown trout. It appears likely the changed ecosystem is now less favorable to salmonid stocking than before, and that spring-yearling stocking is now especially disadvantaged. The current low harvest of brown trout (the estimated harvest from all Michigan ports in Lake Huron was only 1,129 in 2005 and 370 in 2006) is far below the level of an economically viable put-grow-take stocking program.

Matching predator stocking with periods of prey availability is a widely accepted management practice (Ney and Orth 1986). The June stocking window for brown trout in Lake Huron was chosen to coincide with the abundance of alewives, not to supply the stocked trout with immediate prey, as in Ney and Orth (1986), but so that the alewives would provide alternative prey for walleyes, cormorants, and other predators that otherwise would eat the stocked brown trout (Johnson and

Rakoczy 2004). Large aggregations of spawning alewives no longer exist; therefore brown trout stocking during June is no longer synchronous with prey availability in Lake Huron. Since 2005, emerald shiners have reached abundance levels not seen in decades (Schaeffer et al. 2008). Emerald shiners move to nearshore areas during fall, especially harbors and tributary mouths, which they occupy until early spring (Scott and Crossman 1973; Eddy and Underhill 1974). This could represent a new 'window' of opportunity for stocking fall-yearling trout. The abundance of emerald shiners could offer both alternative prey for walleyes and other predators and an immediate food supply for fall-stocked yearling brown trout. Fall yearling brown trout would be suitably sized (~250 mm) to consume the shiners, which are in the range of 40–80 mm in total length. Whether the current abundance of emerald shiners will persist in future years is uncertain, however.

Almost all fish propagated by Michigan hatchery facilities are stocked during spring. Our findings, and an absence of recent literature on the subject, suggest there is a need to evaluate other life stages and times of year (windows) for salmonid put-grow-take stocking. The need is especially acute for Lake Huron, where there has been fundamental change in the fish community, including a nearly recovered, self sustaining walleye population in Saginaw Bay (Fielder et al. 2007; Bence et al. 2008) and collapse of the principal prey species (the alewife). Since 2006, walleye abundance has risen in the main basin of Lake Huron as well, including Thunder Bay (Johnson et al. 2008). Native predator numbers have risen to the point that quite possibly no stocking strategy is capable of overcoming the increased predation on recently stocked fingerling- or yearling-sized brown trout. The problem is especially acute with brown trout because of their tendency to occupy nearshore habitats frequented by walleyes.

The results of this study were equivocal. Fall yearlings produced higher return rates than spring yearlings at Thunder Bay and cost effectiveness of the two stocking strategies was similar there. At Tawas Bay, spring yearlings clearly outperformed fall yearlings by all measures until the final year of study. By 2003 it was clear neither stocking strategy was producing acceptable returns at either site.

Current conditions (2008) of the Lake Huron ecosystem may be more favorable for fall-stocked yearling brown trout than those prevailing during the study period, at least in Thunder Bay. Cormorant numbers in Thunder Bay are currently less than half those of the study period and should continue to decline in response to population management, which has been operative since 2006. The resurgence of emerald shiners and their shoreward migration during fall, if sustained in future years, may fill a void in prey availability caused by the alewife collapse. Thus, the yearling brown trout stocking window of opportunity, if there is one, may now be in October, at least in Thunder Bay.

We recommend consideration of the following options, in descending order of priority, for future management of brown trout in Lake Huron:

1. Cease stocking brown trout spring yearlings because the alewife stocking window no longer exists and the costs of the program vastly exceed benefits derived. The number of brown trout harvested lakewide in 2005 and 2006 was 0.23% of the number stocked compared with near 10% in the early 1970s.
2. Consider stocking relatively low numbers of brown trout in October at Thunder Bay and perhaps Tawas Bay to determine whether reasonable return rates from fall yearlings are now achievable given the current high numbers of emerald shiners at these ports. Reduce cormorant numbers in Thunder Bay to 1989 population levels, which will enhance survival of brown trout during spring of the year after stocking. Expand the fall stocking program to other ports if these experimental stockings produce a reasonable return to creel. We suggest as one possible return criterion that at least 0.6 kg of fish be harvested for each kg stocked, a return rate similar to that in Thunder Bay during1989–2003. However a lower return rate of 0.3 kg harvested per kg stocked, representing about 500 2.5-kg creeled fish from 20,000 fall

yearlings stocked annually, would be acceptable for Thunder Bay as long as there is a Brown Trout Festival there.

3. Should experimental stocking during fall fail to produce acceptable return rates, eliminate stocking of brown trout altogether in Lake Huron.

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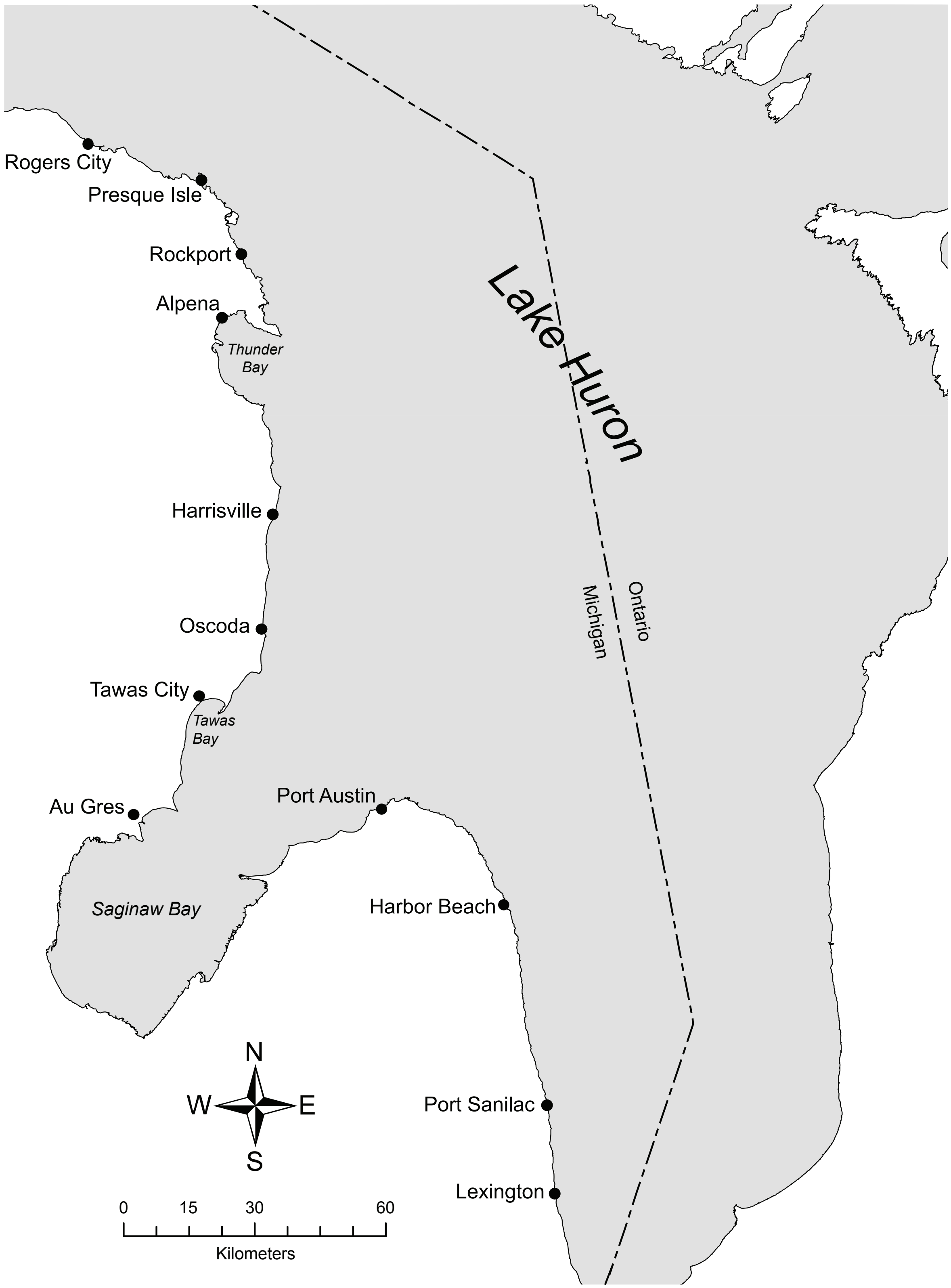

Figure 1.–Locations of Thunder Bay and Tawas Bay study sites and the 10 creel survey sites (black dots) on Lake Huron.

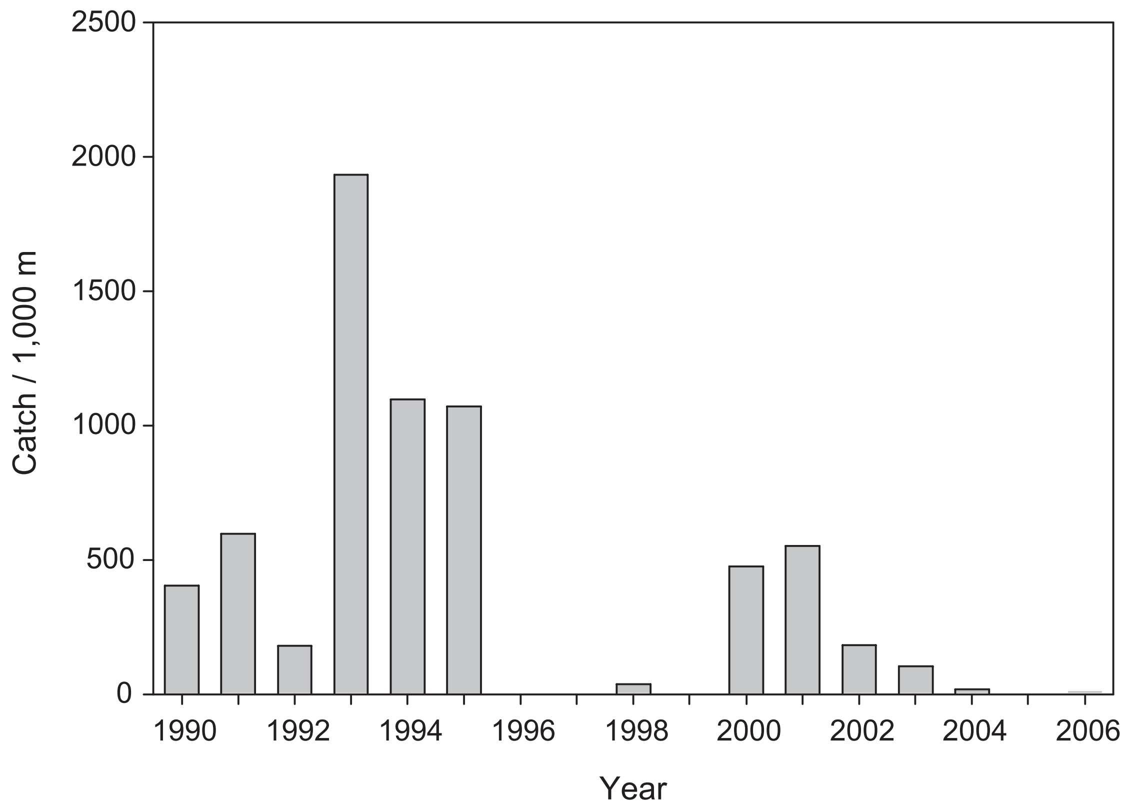

Figure 2.–Alewife catch per unit effort (CPUE) in graded-mesh gill nets set during spring, 1990–2006, Thunder Bay (surveys not conducted in 1996, 1997, and 1999).

Table 1.–List of fish species referred to in this report.

Common name	Scientific name
Alewife	*Alosa pseudoharengus*
Brown trout	*Salmo trutta*
Burbot	*Lota lota*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Emerald shiner	*Notropis atherinoides*
Freshwater drum	*Aplodinotus grunniens*
Gizzard shad	*Dorsoma cepedianum*
Lake trout	*Salvalinus namaycush*
Lake whitefish	*Coregonus clupeaformis*
Longnose sucker	*Catostomus catostomus*
Northern pike	*Esox lucius*
Rainbow trout	*Oncorhynchus mykiss*
Rock bass	*Ambloplites rupestris*
Round goby	*Neogobius melanostomus*
Sea lamprey	*Petromyzon marinus*
Smallmouth bass	*Micropterus dolomieu*
Walleye	*Sander vitreum*
White sucker	*Catostomus commersoni*
Yellow perch	*Perca flavescens*

Table 2.–Number of yearling brown trout stocked and estimated harvest, 1971–2006, Thunder and Tawas bays, Lake Huron. Dashes (–) represent missing data. Effort = angler hr x 1,000; CPE = catch per angler hr.

	Thunder Bay[a]				Tawas Bay			
Year	Harvest	Effort	CPE	Stocked	Harvest	Effort	CPE	Stocked
1971	200	–	–	0	–	–	–	–
1972	150	–	–	70,000	–	–	–	–
1973	900	–	–	120,000	–	–	–	–
1974	7,000	–	–	57,000	–	–	–	–
1975	7,330	116.8	0.063	60,000	–	–	–	–
1976	3,715	66.6	0.056	75,000	–	–	–	–
1977	4,655	81.3	0.057	75,000	–	–	–	–
1978	3,504	46.4	0.076	32,000	–	–	–	–
1979	400	35	0.011	25,000	–	–	–	10,000
1980	400	35	0.011	25,000	–	–	–	10,000
1981	400	35	0.011	25,000	–	–	–	10,000
1982	400	35	0.011	0	–	–	–	0
1983	400	35	0.011	100,000	–	–	–	10,000
1984	400	35	0.011	99,781	–	–	–	5,000
1985	1,803	50.4	0.036	75,000	–	–	–	38,500
1986	3,873	56.5	0.068	102,973	6,782	370.6	0.018	10,050
1987	3,107	72.3	0.043	73,567	1,445	316.1	0.005	10,000
1988	656	69.6	0.009	100,273	578	281.1	0.002	30,022
1989[b]	na	na	na	100,000	127	197.6	0.001	20,000
1990[b]	na	na	na	95,032	na	na	na	20,008
1991	500	58.2	0.007	118,202	205	166.9	0.001	19,500
1992	2,284	79.9	0.025	109,968	310	185.6	0.002	19,500
1993	3,908	89.6	0.038	113,133	286	100.2	0.003	41,389
1994	3,698	108.8	0.031	125,864	1,864	73.2	0.023	38,613
1995	3,524	143.3	0.022	114,488	3,805	128.6	0.028	32,288
1996	2,069	135.6	0.014	89,832	4,647	170.7	0.027	30,398
1997	896	112.7	0.008	120,270	1,354	121.4	0.011	35,019
1998	869	79.1	0.010	126,595	776	82.9	0.009	23,649
1999	161	52.3	0.003	110,411	671	68.6	0.010	35,000
2000	330	65.4	0.005	28,043	1,030	93.1	0.011	15,000
2001	56	40.8	0.001	108,384[c]	460	94.5	0.005	93,415[c]
2002	277	45.2	0.005	102,281[c]	2,019	155.4	0.013	109,721[c]
2003	677	46.4	0.012	85,000[c]	2,361	181.2	0.013	99,554[c]
2004	265	56.6	0.004	40,000	568	93.7	0.006	50,000
2005	102	31.9	0.003	0	709	80.3	0.009	50,000
2006	5	26.4	0.000	0	107	50.6	0.002	57,600

[a] Data prior to 1986 from Johnson and Rakoczy (2004).

[b] Standard creel survey activities were not conducted in 1989 or 1990 at Thunder Bay nor in 1990 at Tawas Bay.

[c] Includes both spring- and fall-stocked yearlings.

Table 3.–Number, size, and biomass of marked spring- and fall-yearling brown trout (Seeforellen strain) stocked at two study sites, 2001–03. Fin clip designations are left ventral (LV) and right ventral (RV).

Year stocked	Site	Stocking season	Clip	Mean total length (cm)	Number stocked	Weight stocked (kg)
2001	Tawas	Spring	LV	19.1	60,000	4,671
		Fall	RV	25.8	33,415	6,480
	Thunder Bay	Spring	LV	19.3	72,967	5,851
		Fall	RV	25.6	35,417	6,584
2002	Tawas	Spring	LV	18.8	79,328	5,815
		Fall	RV	24.9	30,393	5,231
	Thunder Bay	Spring	LV	19.0	65,737	5,006
		Fall	RV	24.8	36,544	6,253
2003	Tawas	Spring	LV	19.2	66,000	5,179
		Fall	RV	24.8	33,554	5,676
	Thunder Bay	Spring	LV	19.4	48,000	3,880
		Fall	RV	24.8	37,000	6,324

Table 4.–Three years of experimental brown trout stocking and cumulative recreational harvest estimates from two stocking strategies, based on Lake Huron creel surveys conducted from 2002 through 2005.

							Expected ratios [a]		Measured ratios [a]	
Year stocked	Stocking season	Number stocked	Weight (kg) stocked	Observed in creel	Returns/ 50,000 stocked	Returns/ 1,000 kg	number	adjusted for kg stocked	number	adjusted for kg stocked
					Northern ports [b]					
2001	Spring	72,967	5,851	13	8.91	2.22	0.33	0.53	0.59	0.56
	Fall	35,417	6,585	19	26.82	2.89				
2002	Spring	65,737	5,006	26	19.78	5.19	0.36	0.56	0.57 [c]	0.52
	Fall	36,544	6,253	35	47.89	5.60				
2003	Spring	48,000	3,880	5	5.21	1.29	0.44	0.62	0.44	0.33
	Fall	37,000	6,325	4	5.41	0.63				
					Southern ports [d]					
2001	Spring	60,000	4,671	96	80.00	20.55	0.36	0.58	0.23 [b]	0.18 [b]
	Fall	33,415	6,480	29	43.39	4.48				
2002	Spring	79,328	5,815	117	73.74	20.12	0.28	0.47	0.12 [b]	0.13 [b]
	Fall	30,393	5,231	16	26.32	3.06				
2003	Spring	66,000	5,179.3	16	12.12	3.09	0.34	0.52	0.47	0.44
	Fall	33,554	5,676.2	14	20.86	2.47				

[a] Expected ratios were number or weight of fall-stocked divided by total of test fish stocked.
[b] Northern ports: Harrisville, Alpena, Rockport, Presque Isle, and Rogers City.
[c] Significant difference, binomial test, $p \leq 0.05$.
[d] Southern ports: Oscoda , Tawas, AuGres, Port Austin, Harbor Beach, Port Sanilac, and Lexington.

Table 5.–Averages of length and weight at age of brown trout from two treatments, stocked during 2001–03, observed in the recreational harvest during July and August, 2002–05, northern ports[a], Lake Huron.

Age	Treatment	Length (mm)	Sample size	Standard deviation 1ength	Weight (kg)	Sample size	Standard deviation weight
2	Spring yearling	555	11	64	2.38[b]	15	0.86
	Fall yearling	581	21	82	3.05[b]	28	1.07
3	Spring yearling	701[b]	11	54	4.60[b]	10	1.08
	Fall yearling	651[b]	12	44	3.74[b]	19	0.91
4	Spring yearling	698	3	66	4.68	3	0.73
	Fall yearling	787	1		5.73	1	

[a] Harrisville, Alpena, Rockport, Presque Isle, and Rogers City.
[b] Significant difference between treatments.

Table 6.–Length at age of brown trout from two treatments, stocked over a period of 3 years, observed in the recreational harvest during July and August, 2002–05, southern ports[a], Lake Huron.

Age	Treatment	Length (mm)[b]	Sample size	Standard deviation 1ength
2	Spring yearling	542	22	78
	Fall yearling	566	6	53
3	Spring yearling	703	3	12
	Fall yearling	713	7	25
4	Spring yearling		0	
	Fall yearling		0	

[a] Oscoda, Tawas, AuGres, Port Austin, Harbor Beach, Port Sanilac, and Lexington.
[b] There were no significant differences between treatments.

Table 7.–Catch per 1,000 m of graded-mesh gill net during early June, 2000–06, Thunder Bay, Lake Huron.

Year	Alewife	Gizzard shad	Northern pike	Burbot	Freshwater drum	Channel catfish	Round whitefish	Brown trout	White and longnose suckers	Smallmouth bass	Yellow perch	Walleye	Total, excluding alewives
2000	474.7	26.2	0.0	2.2	62.3	19.7	4.4	0.0	62.3	1.1	13.1	84.2	274.5
2001	551.2	35.0	0.0	0.0	12.0	156.4	1.1	0.0	13.1	1.3	1.1	60.2	278.9
2002	182.4	5.2	0.0	0.0	6.6	9.2	0.0	1.3	14.4	0.0	0.0	35.4	72.2
2003	105.0	21.0	3.9	0.0	7.9	9.2	0.0	1.3	5.2	0.0	0.0	59.1	107.6
2004	18.4	3.9	1.3	0.0	15.7	7.9	0.0	0.0	19.7	0.0	0.0	78.7	127.3
2005	3.3	0.0	0.0	0.0	3.9	15.7	0.0	0.0	7.9	0.0	0.0	47.2	74.8
2006	10.9	0.0	0.0	0.0	6.6	6.6	3.3	1.1	14.2	0.0	1.1	44.8	77.7

Table 8.–Diets of predator fish at time of spring stocking, expressed as number of prey items consumed, Thunder Bay, 2001–03.

Species	Number sampled	Void	Unidentified	Mayflies	Crayfish	Round goby	Alewife	Trout perch	Johnny darter	Brown trout	Spottail shiner
Northern pike	8	4				2					
Channel catfish	159	55	20	200	3	75	1	15			
Freshwater drum	23	17				45			2		
Brown trout (age ≥ 2)	2	1				4					
Smallmouth bass	2	1	3								
Walleye	127	114					17			5	13

Table 9.–Catch, catch/1,000 m of net (CPUE), and stomach contents of fish sampled in fall 2001 gill-net survey, Thunder Bay, Lake Huron.

Species	Catch	CPUE	Mean length (mm)	Number void[a]	Unidentified fish remains	Diptera	Crayfish	Rainbow smelt	Round goby
Brown trout (age ≥ 2)	14	5.6	472	12		present in 1	1		
Brown trout yearlings	54	21.6	276	37	2	present in 15			
Chinook salmon	2	0.8	826	2					
Gizzard shad	5	2.0	388	na					
Lake trout	15	6.0	672	14	1				
Lake whitefish	43	17.2	531	43					
Longnose and white suckers	6	2.4	396	na					
Rainbow trout	1	0.4	718		1				
Rock bass	1	0.4	130	na					
Walleye	7	2.8	516	3	1			2	1

[a] na = stomachs not examined.

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