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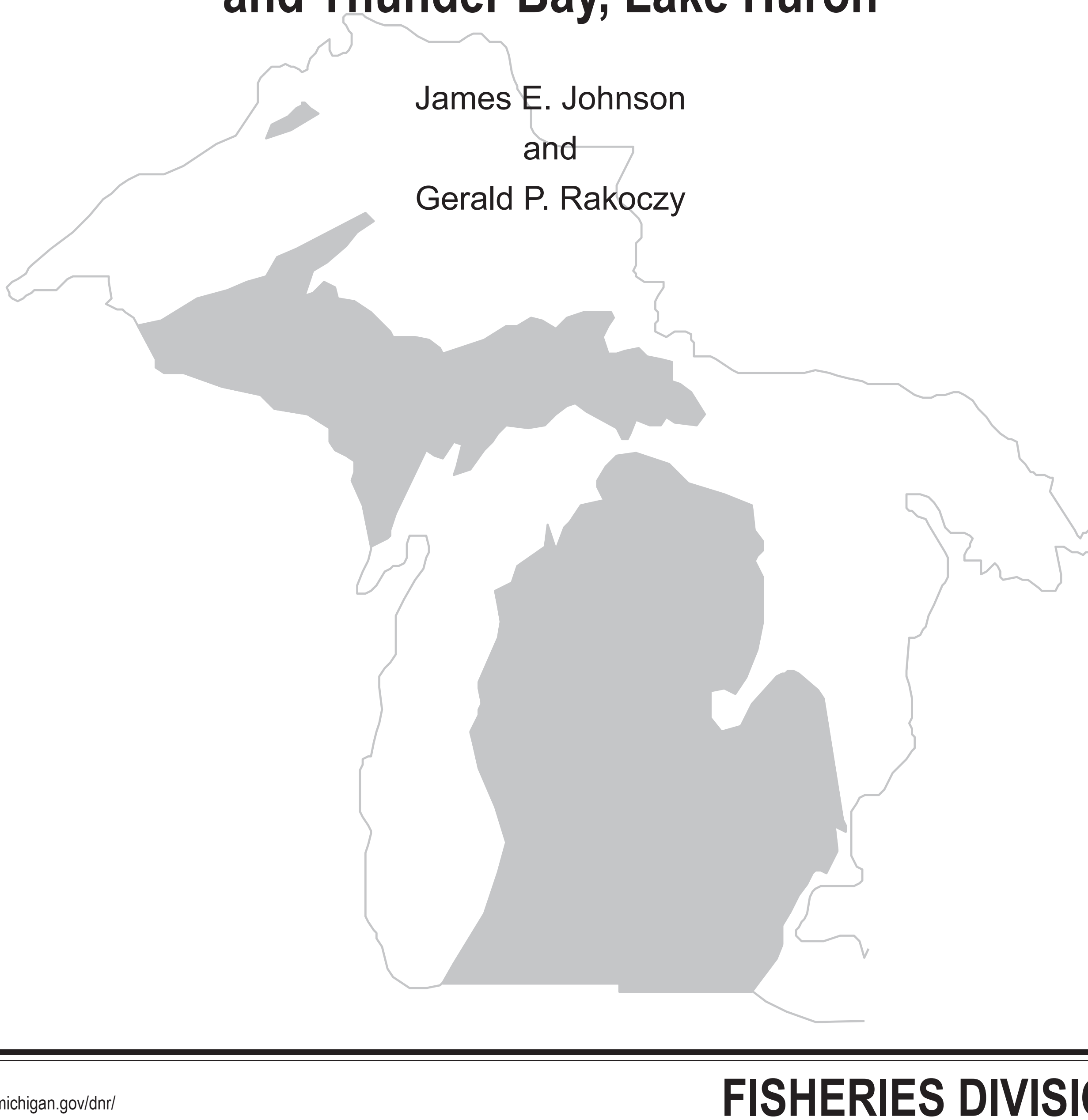

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Investigations into Recent Declines in Survival of Brown Trout Stocked in Lake Charlevoix and Thunder Bay, Lake Huron

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*Abstract.–*Sharp declines in the Thunder Bay, Lake Huron and Lake Charlevoix brown trout fisheries prompted investigations into the causes of brown trout failures in these waters and possible solutions. Both Thunder Bay and Lake Charlevoix are located in the northern part of Michigan's Lower Peninsula. Test netting and diet studies of predators and prey in Thunder Bay during 1990 showed that piscivorous fish, particularly walleyes, consumed recently stocked brown trout, but that spawning aggregations of alewives during June appeared to buffer predation on stocked trout by offering ample alternate prey. The stocking date for brown trout, which had been early May, was therefore changed to mid-June in 1992. Two strains of brown trout, Wild Rose and Seeforellen, were selected for field evaluation based on evidence of satisfactory lacustrine performance elsewhere, and programmed for testing in Thunder Bay and Lake Charlevoix. These strains were also compared with Plymouth Rock strain, which had been stocked in both systems prior to the study. Both Seeforellen and Wild Rose strains produced greater returns and faster growth than Plymouth Rock strain. Seeforellen and Wild Rose strains were similar to each other with respect to returns to creel, growth rates, and longevity in the fishery. However, there was evidence that Seeforellen strain produced slightly better results in Thunder Bay. The brown trout fishery in Thunder Bay rebounded with successful stockings in 1991–95, but declined again as a consequence of poor survival of trout stocked after 1995. The short-term recovery was attributed to the later stocking window and deployment of the new test strains of brown trout. The brown trout failure after 1995 appeared to be caused by declining alewife abundance, which essentially "closed" the June stocking window. Predation on brown trout was probably exacerbated by an 8.4-fold increase in double-crested cormorant *Phalacrocorax auritus* numbers in the Thunder Bay area between 1989 and 1997. Offshore stocking had no measurable effect on survival of the 1996 and 1997 yearling cohorts; both nearshore and offshore treatments survived poorly in both years. The brown trout niche in Thunder Bay appeared to be tenuous. Zooplankton and other prey were scarce for age-1 brown trout. Diet of age-1 brown trout was chiefly terrestrial insects because the trout were too small to utilize the abundant adult alewives. Longevity of brown trout in the fishery was relatively short and few survived past age four. Thus, once recruited at age two to a size sufficient to feed on alewives, brown trout contributed to the fishery only one or two more years. Two successive year

class failures therefore were sufficient to cause collapse of the fishery. Unless alewives recover, predators decline, or another prey species (such as the round goby, a recent invader) alter the food web in a way that favors brown trout, the niche for put-grow-take brown trout management of Thunder Bay may have disappeared.

Introduction

Lakes Huron and Michigan host what are perhaps the world's largest put-grow-take salmonine recreational fisheries (Whelan and Johnson 2004). Natural recruitment failures were caused by sea lamprey (see Table 1 for scientific names of fish) 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; Eshenroder et al. 1995; Johnson et al. 2004; Whelan and Johnson 2004). The 1960s and 1970s saw rehabilitation programs begin 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; Eshenroder et al. 1995; Kocik and Jones 1999; Whelan and Johnson 2004). These changes led to ecologically balanced fish communities, recreational and commercial fisheries valued in excess of $2 billion 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 remain principally supported by stocking. Self-sustaining naturalized populations of most introduced salmonine species have failed to develop. Where naturalized populations have developed, stocks remain recruitment limited (Keller et al. 1990; Whelan and Johnson 2004). In the case of brown trout, reproduction is limited to a few isolated populations. Thus, many of the salmonine fisheries of lakes Michigan and Huron, brown trout in particular, are dependent on continued success of put-grow-take stocking programs (Whelan and Johnson 2004).

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

- *A change in genetic strain of brown trout used for stocking may have contributed to a decline in post-stocking survival.* The Michigan Department of Natural Resources discontinued its own “Harrietta” strain brown trout broodstock in 1984. This strain of brown trout was no longer stocked after 1985 and other strains of brown trout were substituted.
- *An increase in predation rates on stocked trout contributed to a decline in post-stocking survival.* By the 1980s, walleyes appeared to be recovering in many locations in western Lake Huron, including Thunder Bay. Double-crested cormorants *Phalacrocorax auritus*, blue herons *Ardea herodias*, herring gulls *Larus argentatus*, and other fish-eating bird populations were also thought to be increasing. Thus, predation by recovering piscivorous birds and fish may have contributed to the declining recreational fishery.

This study was initiated to test if: 1) conditions of the receiving waters, such as food availability and predation on recently stocked yearling brown trout, were contributing to observed declines in the recreational harvest of brown trout; 2) the decline in stocking success and return to creel was associated with strains chosen for stocking; 3) there were differences in growth, longevity, and spawning dynamics of strains chosen for stocking; and 4) return to creel of brown trout stocked in Thunder Bay was enhanced by transporting the trout to offshore stocking locations. Similar problems with stocking success were evident at Lake Charlevoix, an inland lake connected to Lake Michigan; thus, certain elements of the study were replicated there.

Study Sites

Thunder Bay, Lake Huron is located in the northeast part of Michigan's Lower Peninsula; Lake Charlevoix is located in the northwest (Figure 1). Thunder Bay measures approximately 22,000 ha and has a maximum depth of 27 m. The study area in Thunder Bay was within a 7-km radius of the mouth of the Thunder Bay River in Alpena. Lake Charlevoix is an inland lake connected to Lake Michigan through adjacent Round Lake and its outlet channel. Lake Charlevoix is 6,900 ha in area and has a maximum depth of 37 m. Both are oligotrophic systems.

Strain Selection and Stocking

Criteria for selecting strains of brown trout to be tested were:

- Evidence of satisfactory performance in lacustrine waters
- Piscivorous and long-lived, therefore likely to take advantage of adult alewives, the principal prey species in Thunder Bay during the study period
- Eggs available in adequate quantity
- Free of reportable pathogens—the donor broodstock must be certified by a qualified pathologist as free from restricted pathogens, as defined by the Great Lakes Fisheries Commission Disease Control Committee (Horner and Eshenroder 1993)
- Donor eggs adequately represent the genotype and genetic diversity of the donor stock

In 1990, when we made our selection, there was little published literature regarding brown trout strains that met these criteria. Flaming Gorge strain and Soda Lake strain brown trout produced good fisheries for exceptionally large brown trout in Flaming Gorge Reservoir during the 1970s but that fishery declined as competing fish species colonized the reservoir (Flaming Gorge Reservoir Post Impoundment Investigations, Federal Aid Project F-28-R annual reports, Salt Lake City, Utah). Wild Rose strain brown trout stocked in Green Bay, Wisconsin, had for many years produced consistently good fishing for large brown trout (Brian Belonger, Wisconsin Department of Natural Resources, Green Bay, personal communication and unpublished data). There was an ample supply of eggs available from Wild Rose Hatchery, Wisconsin and they were certifiably free of restricted pathogens. Seeforellen strain brown trout had been imported from alpine lakes of West Germany by New York Department of Environmental Conservation and Adelphi University during 1979–86. Seeforellen strain brown trout were reported to be lacustrine, piscivorous, and distributed across the subalpine regions of western Europe, where brown trout reach exceptionally large sizes (Garrell and Strait 1982). Eggs were available from New York Department of Environmental Conservation and they were certifiably free of restricted pathogens. Plymouth Rock was the strain from which eggs were most frequently available from the U.S. Fish and Wildlife Service hatchery system and was therefore the strain most often used for stocking Thunder Bay and Lake Charlevoix during the late 1980s. The performance of Plymouth Rock strain brown trout had not been evaluated in Michigan, but declines in the Thunder Bay and Lake Charlevoix brown trout fisheries during the period this strain was stocked suggested it might be performing poorly in these waters.

Wild Rose and Seeforellen strains met the criteria for testing in Thunder Bay. Plymouth Rock strain was scheduled for stocking in Thunder Bay and Lake Charlevoix until the test strains became available. Seeforellen strain was available in 1991 but Wild Rose strain was not available until 1992. We therefore chose to compare Seeforellen performance with that of Plymouth Rock in 1991 at both Lake Charlevoix and Thunder Bay. Seeforellen and Wild Rose strains were stocked for paired comparisons in Thunder Bay in 1992–95. A similar stocking plan was carried out in 1992–95 at Lake Charlevoix except that a paired stocking of

Plymouth Rock and Wild Rose strains was made in Lake Charlevoix in 1993. Thunder Bay stockings are given in Table 3; Lake Charlevoix stockings are in Table 4.

Thunder Bay Study

Methods for Thunder Bay

Stocking, Fish Health, and Fin Clip Quality Control.—The test strains were cultured at Oden State Fish Hatchery. The hatchery was asked to equalize size and quality of test strain pairs. Test strains were marked using either left or right ventral fin clips. Fin clips were administered during fall, approximately six months prior to stocking. Beginning in 1991, based on fish population studies in 1990, the stocking window for Thunder Bay was moved from early May to the second week of June. The test groups were transported by boat from hatchery trucks to stocking sites approximately 3 km offshore. The research vessel RV *Chinook* was equipped with an 8,000-L fish transport tank supplied with water agitators and an oxygen diffusion system. Fish were unloaded through a discharge tube 10-m in length and anchored on one end so that the fish were delivered to the bottom in water depths of 6–9 m. The stocking period was mid June.

In 1996 and 1997, paired comparisons were made of offshore (boat) and nearshore (truck) stocking methods using Seeforellen strain brown trout. In those years, half the annual allotment of trout for Thunder Bay was transported approximately 3 km offshore. Nearshore stocking was done by releasing the other half of the allotment of trout directly from the truck in the beach zone. As with the strain evaluation, boat- and truck-stocked brown trout were marked with distinctive pelvic fin clips (Table 5).

In 1991 and 1992, quality control samples were taken at the hatchery from three to six weeks prior to stocking. In 1993, 1994, and 1995, quality control samples were taken at delivery to Thunder Bay. Quality control indexing was done using the Goede Fish Health Index (Goede 1989) and a fin-clip quality rating. The Goede Fish Health Visceral Fat Index (VFI) was used to categorize mesenteric fat levels based on visual observation of fat surrounding the pyloric caeca. VFI is a direct ranking of fat reserves and, unlike condition factor, is not biased by recent feeding history. VFI rankings were applied in this study as follows:

0—Zero or near zero fat surrounding pyloric caeca;
1—Nearly 25% of each caecum covered with fat;
2—Nearly 50% of each caecum covered with fat;
3—Nearly 75% of each caecum covered with fat;
4—Near 100% of each caecum covered with fat.

A VFI near three is considered desirable, providing adequate fat reserves for post-stocking transition to the wild (R. Goede, Utah Division of Wildlife Resources, personal communication).

Fin clips were assigned to one of five categories: 1) good, fin nearly completely removed; 2) fair, noticeable regeneration but likely to be detectable over the life of the fish; 3) poor, likely to regenerate beyond recognition; 4) no clip; 5) wrong (opposite) clip.

Assess Diets and Conditions of Receiving Waters.—The fish community of Thunder Bay was sampled during spring, 1990–92, using gill nets to identify seasonal conditions that might be especially favorable for stocking. Gillnetting was also conducted during and after stocking from 1993–95 with the primary objective of identifying piscine predators of brown trout and examining diets of these predators in Thunder Bay. Netting was conducted as part of another study in 1998, 2000, and 2001 during and after stocking. Alewife numbers were indexed in all these survey efforts. Nets 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 12 m. A unit of effort for predator fish was defined as an overnight set of 76 m of such gear. 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 stomach were counted and identified. Alewife abundance was indexed as the number of alewives caught per 30 m of small mesh (38- and 51-mm mesh combined).

In 1990 and 1991, plankton was sampled in Thunder Bay using a 1.0-m hoop net with 1.4-mm mesh. Three 10-min tows were taken at each of three depths, 1.5, 3, and 5 m. The net was held at the selected depth with a depressor plate mounted on the bottom of the net hoop. The net was towed at a speed of 1.1 m/s. The objective of plankton sampling was to describe temporal relative abundance of zooplankton large enough (>1.4-mm body length) to be prey for newly stocked brown trout so that stocking dates could be adjusted to take advantage of any peak zooplankton abundance.

Determine Return to Creel of Stocked 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. Effort was measured using randomly scheduled instantaneous counts of shore anglers, pier anglers, and boat trailers at boat access sites. 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). Biological data collected from the recreational harvest included species composition, fin clip, length, weight, and scale samples for age determination. Creel census clerks were required to take biological data from all brown trout encountered. Biological data were taken from subsamples of other species in the observed catch. The creel census was conducted from 1 May–30 September at most ports but from 1 April–31 October of each year, 1991–2000, at Thunder Bay. In addition, the annual Alpena Brown Trout Festival offered an opportunity to collect biological data from a robust sample of harvested brown trout during mid–July. The Festival data, being from a discrete time of year, were valuable in making annual comparisons of growth and condition parameters between the strains. Biological data collected from this Festival included brown trout diets, recorded as number of prey organisms consumed by species.

Age at Maturity.—One hypothesis in selection of the Seeforellen strain was that its reputed longevity could result in later age at maturity or lower energy expenditures during spawning. Weber (1988) determined spawning-associated mortality of the Michigan Harrietta strain brown trout was high in Thunder Bay. Wisconsin studies suggest total annual mortality of mature Wild Rose brown trout may exceed 85% (Wisconsin Department of Natural Resources, unpublished data). We assessed rate of maturation of Seeforellen and Wild Rose strains by coding stage of maturity of angler-caught brown trout observed during the 1993–97 Brown Trout Festivals. To evaluate strain-specific differences in energy directed toward spawning, ovary weights were compared to somatic weights from Wild Rose and Seeforellen brown trout gillnetted during the fall, 1993–95. Visceral fat indices were also recorded from these ripe or nearly ripe fish. Effort consisted of overnight sets of gill nets composed of 30-m panels of 90-, 114-, 127-, and 140-mm mesh (stretch measure). Netting was conducted during a three-week period in October 1992–96.

Results for Thunder Bay

Stocking, Fish Health, and Fin Clip Quality Control.—Fish health indices revealed few pronounced differences in the quality of test strains at time of stocking within any study year. Total lengths of each year-class pair at time of autopsy were similar each year of the study, although Wild Rose strain was significantly larger in length and weight (a difference of 7-mm total length; t-test, $P = 0.034$) than Seeforellen strain in 1995 (Table 6). Condition factors were significantly different between strains each year, but only in 1993 were they lower than 0.99. Visceral fat indices differed significantly in some years but were above 3.0 in all but the 1994 Wild Rose cohort, which averaged 2.6. The lower condition factor of Seeforellen strain in 1993 was accompanied by an average visceral fat index of 3.3; thus in spite of relatively lean body conformation that year, these fish carried above averaged fat reserves. None of the indices suggested any test group was compromised in terms of size or condition at time of stocking.

In 1991, fin clip quality was poor, especially for Seeforellens. Therefore, fin clipping was repeated during the two weeks prior to stocking. Fin clip quality was again measured along with total length of the fish on the day each lot of fish was stocked into Thunder Bay. The data for

1991–95 are summarized in Table 7. As in the fish health indexing, total lengths at time of stocking were similar for each study pair. Lengths differed significantly (t-test, $P < 0.05$) in 1991 and 1995, but in neither case were the differences between study pairs more than 9 mm.

The number of study fish stocked in Thunder Bay with detectable marks was computed as a product of number stocked and the proportion with detectable marks. Study fish with no marks or poor marks that were likely to regenerate were considered to have undetectable marks. Numbers of study fish with detectable marks released into Thunder Bay are given by strain and year class in Table 3.

Fin erosion was included as an element of fish quality monitoring in 1992–95. Fin erosion was the only fish health index that consistently departed from normal. Overall, active fin erosion was found on at least one fin for 30% of the study fish and erosion was accompanied by bleeding or hemorrhages among 11% of the study fish (Table 8). Within each cohort pair, there were significant differences in the incidence of fin erosion ($P \leq 0.01$, chi-square test). In 1992 and 1993, the Seeforellen strain displayed the highest incidence of active fin erosion, while the opposite was true in 1994 and 1995. In every year, the incidence of hemorrhaged fins was higher in the Wild Rose strain. Active fin erosion and fin erosion accompanied by bleeding were observed in more than 25% of the test fish in all groups with the exception of the 1994 Seeforellen test group, which had almost no evidence of active fin erosion (Table 8). Incidence of fin erosion was especially pronounced for the Seeforellen strain in 1992. Fin erosion combined with bleeding fins was especially pronounced for Wild Rose strain in 1995.

Assess Conditions of Receiving Waters.— From 1990 to 1995, 130 gill net sets were fished, totaling 9,707 m of effort. An additional 43 gill net sets were made in 1998, 2000, and 2001, totaling another 3,383 m of effort. The post-1995 results are reported here, even though they were done as part of another project, because of the additional insights they provide. During the 1990–2001 period, 3,205 fish were sampled in gill nets, representing 26 species. The most abundant species in samples were alewives, brown trout, walleyes, and channel catfish (Table 1). Among fish larger than 400-mm total length, walleyes were most abundant, composing 53% of the catch.

The objective of sampling in 1990 was to assess predator-fish abundance, prey availability, and diets during the spring stocking period for use in determining the optimal period of the year to stock brown trout. In that year, 37 graded-mesh gill net sets were fished at weekly intervals before, during, and after stocking for a total of 2,852 m of effort. Over the entire study period, the smallest piscivorous fish observed to have eaten a stocked brown trout was 482 mm in total length. Thus, we defined potential consumers of recently stocked brown trout to be any piscivorous fish longer than 480-mm total length. In 1990, 163 of these larger piscivorous fish, composed of six species, were taken in gill nets, of which 105 were walleyes. In addition, alewives were regularly taken in the smaller mesh sizes. Although predator fish catch rates appeared to vary with date without trend, alewife catch rates were highest after June 10 (Figure 2). This abundance of alewives in late spring suggested a stocking window-of-opportunity occurred when alewives were abundant enough to buffer the effects of predation on stocked brown trout. Thus, stocking was scheduled for the second week of June for 1991–95.

In 1990, stocking was conducted on 8–10 May. A total of 19 recently stocked brown trout were sampled in nets in 1990. Stocked brown trout also appeared in the diets of walleyes, burbot, channel catfish, and adult brown trout sampled in 1990 (Table 9), and composed over 10% of the diet by number in walleyes during the week after the brown trout were stocked (Table 10). The diet of walleyes and other predators appeared to shift from smelt to alewives over the spring sampling period in 1990 and the number of void stomachs declined as numbers of alewives in the diets increased (Table 10).

Walleye catch, when expressed as a function of average date of capture (Figure 3) over the 1990–2001 period, appeared to vary without trend, unlike alewife numbers, which increased over the spring period (Figure 2). Alewives predominated in the diet of walleyes in 1993–95

(Table 11), but brown trout continued to be observed in walleye stomachs, even though the brown trout were stocked during periods of high alewife abundance. In 1990–2001, 694 walleyes were sampled, of which 20 had at least one brown trout in their stomachs. Those that had eaten brown trout averaged 603 mm in total length and were larger (t-test, $P < 0.01$) than the average of all walleyes, which was 488 mm.

For the period 1990 through 2001, annual June walleye catch per unit effort (CPUE) varied without trend (Figure 4). The highest catch rate was in 1994 (37) and the lowest in 1996 (11). During the same period, alewife CPUE appeared to peak in 1993 and 1994 and was relatively low at the beginning and the end of the 1990–2001 time series (Figure 5).

Zooplankton tows revealed a near absence of zooplankton and a paucity of ichthyoplankton larger than 1.4 mm in size in Thunder Bay during June and July 1990. Copepod abundance peaked on 6 June and 21 June, when in excess of 300 were taken per 10-minute tow, but none was larger than 1 mm in body length. Ichthyoplankters were rare, but constituted the only significant biomass of suitably sized planktonic prey for brown trout in our samples (Table 12). Thus, large zooplankton appear not to be available as prey for recently stocked brown trout during June or July in Thunder Bay.

Diets of recently stocked brown trout from 1 May to 15 June, 1990–98, were composed principally of terrestrial insects (55%), with little evidence of zooplanktivory (Table 13). Fish composed 6% of the diet and aquatic insects, principally *Hexagenia limbata*, contributed 15%. Although alewives were abundant in Thunder Bay in June and July, most were mature and too large for yearling brown trout to consume. The high proportion of void stomachs (73%) and the lack of suitably large zooplankton and ichthyoplankton in the plankton tows suggest the food supply for young brown trout was relatively scarce during the period after stocking.

Determine Return to Creel of Stocked Trout.—Harvest of brown trout in Thunder Bay rose sharply in 1992, the first year study fish recruited to the creel, remained relatively high through 1995, but then declined in 1996–2001 (Table 2; Figure 5). Brown trout harvest the year after stocking was only weakly correlated with the number stocked ($R^2 = 0.17$) from 1986–2001. Brown trout harvest the year after stocking was more sensitive to alewife gill net CPE in the year of stocking ($R^2 = 0.53$) (Figure 5) than stocking rate. Alewife numbers were relatively low after 1995, as was return to creel of stocked brown trout.

Fin clip compositions of harvested brown trout observed in the Lake Huron creel survey, corrected for fin clip quality, are presented for the strain-comparison study in Table 14 and for the stocking-method study in Table 15. For cohorts stocked in 1991, the ratio of age-2 Seeforellen to Plymouth Rock strain was near expected based on number stocked, but the proportion of Seeforellen returns was significantly higher than expected at age three ($P < 0.001$). In comparison to the Wild Rose strain, Seeforellen strain returned at higher than expected proportions for some years and ages ($P < 0.05$, Table 16), but not others. Overall, Seeforellen tended to return better than the other test strains, sometimes significantly so, while Plymouth Rock and Wild Rose strains produced no instances of significantly better return ratios when paired with Seeforellen strain (Table 16). These results from creel survey biological data were reflected in the ratio of strains officially entered in the annual Brown Trout Festival. The ratio of Seeforellen (right-ventral clip) to Wild Rose and Plymouth Rock strains (left-ventral clip) was significantly higher ($P < 0.01$) than the expected 50% in 1993, 1994, and 1996, but not ($P > 0.05$) in 1995 (Table 17). In 1998, only 155 brown trout were entered in the Brown Trout Festival, the lowest since 1991. The 1997 and 1998 catch included brown trout with left-ventral and right-ventral clips, and trout from both study phases (strain and stocking-method comparisons) were probably represented in those years. However, Festival personnel did not take scales from tournament entries and age and study phase could not be ascertained.

Unfortunately, survival of the 1996 and 1997 stockings of yearling brown trout was too low to obtain adequate sample sizes from the creel survey for the comparison of offshore and nearshore stocking methods. There was little difference between the few returns of brown trout stocked from shore compared to those stocked from the vessel; both test groups had exceptionally low return rates (Table 15).

Study brown trout did not move far from the Thunder Bay study area. Of combined test strain returns, 94% were observed at Alpena, and 97% were observed at Alpena and its adjacent ports of Harrisville and Rockport (Table 18).

Weight and length data were collected from a total of 1,787 brown trout with study fin clips observed in the recreational catch. At ages two and three, Seeforellen strain of the 1991 cohort were longer and heavier ($P < 0.001$) than Plymouth Rock strain stocked the same year (Table 19). Weight–length regressions of the two strains appeared different, with the exponent of the power equation greater for Plymouth Rock than Seeforellen. The higher exponent suggests Plymouth Rock strain become relatively more robust with increasing size than Seeforellen strain. The slopes of the $\log_e$-transformed regressions from the two strains were not significantly different, however ($P = 0.20$) (Table 20). Differences in size and weight–length regressions were less pronounced in the comparisons of Wild Rose with Seeforellen strain. There was no significant difference ($P > 0.9$) between the slopes of $\log_e$ transformed, weight–length regressions (Table 20). However, Seeforellen strain was significantly longer in 7 out of 10 age–cohort comparisons with Wild Rose strain, and was significantly heavier in 5 out of the 10 comparisons ($P < 0.05$). Wild Rose strain was not significantly larger than Seeforellen strain in any of the comparisons (Table 19). Analysis of variance indicated that length and weight were functions of strain ($P < 0.05$); length and weight were also functions of age, and interactions of strain–age and strain–age–cohort for the 1992–95 cohorts of Seeforellen and Wild Rose stockings ($P < 0.05$).

During annual mid-July Brown Trout Festivals of 1993–96, a total of 408 age-2 and age-3 study brown trout were observed. Only 10 study trout were older than age three (Table 21). Data were not collected during the Festival in 1992; therefore, Festival data were not used in growth comparisons of age-2 Plymouth Rock and Seeforellen strains stocked in 1991. Only two age-3 Plymouth Rock strain were observed in the 1993 Festival. For the combined measurements from 1992–95 cohorts, mean lengths were significantly greater ($P \leq 0.01$) at both ages 2 and 3 for Seeforellen than Wild Rose and weights of Seeforellen strain were significantly greater ($P < 0.001$) than Wild Rose strain at age three. Thus, in both the monitored recreational catch and the Brown Trout Festival entries, Seeforellen tended to be heavier and longer at age than Wild Rose strain.

Diets of angler-caught brown trout were tabulated during the 1993–96 Brown Trout Festivals (Table 22). Similar to the gill net assessment samples, alewives were the staple of the diet of age-2 and age-3 brown trout, composing 82% of the identifiable food items in brown trout stomachs.

Assess Age at Maturity.—From 1993 to 1996, we indexed stage of maturity of 283 age-2 and 125 age-3 brown trout during Brown Trout Festivals. A higher percentage of Wild Rose than Seeforellen brown trout matured at age two (Mann-Whitney U, $P = 0.002$), but nearly 100% of both strains were mature by July of their third year (Table 23). Mature age-1 brown trout were observed in fall sampling (Tables 24 and 25). As in the recreational catch, Seeforellen strain brown trout captured in spawning condition during fall gill net assessments were significantly longer and heavier than Wild Rose strain at age two and age three ($P < 0.05$); however, there was no significant difference ($P > 0.05$) in apparent energy reserves, as measured by visceral fat index (Tables 27 and 28). For both age-2 and age-3 females captured in spawning condition, the gonadal-somatic index of Seeforellen strain was slightly below that of Wild Rose strain, but the difference was only weakly significant (t-test, $P = 0.05$) at age three, the estimates suffering from low sample sizes (Table 28). Further sampling may have strengthened these data; however, shortage of staff (vacancy of Assistant Boat Captain position) precluded further fall sampling in 1996. The vast majority of both Seeforellen and Wild Rose brown trout observed in test netting and the creel were ages two and three. Neither strain exhibited a substantial level of survival to age four or beyond.

Lake Charlevoix Study

Methods

Fish Stocking.—As with the Thunder Bay portion of the study, the test strains were cultured at Oden State Fish Hatchery. The hatchery was asked to equalize size and quality of test strain pairs. Test strains were marked using either left or right ventral fin clips administered during fall, approximately 6 months prior to stocking. The test groups were stocked in 1991–95 (Table 4), directly in nearshore waters from hatchery trucks.

Determine Return to Creel of Stocked Trout.—Limited creel surveys were conducted on Lake Charlevoix during 1993–95, when anglers were interviewed to determine catch rate and composition. However, during those years no fishing pressure counts were made to determine total angler effort. During 1996, a creel survey was conducted on Lake Charlevoix from 1 May–30 September to determine the performance of the three selected strains of brown trout. Except for counts of effort, methods for the 1996 creel survey on Lake Charlevoix were similar to those used for Thunder Bay. Rather than shore counts of boat trailers and shore anglers, instantaneous counts of anglers or boats on Lake Charlevoix were made using air flights. Five flights were made each week at randomly selected starting times: one each weekend day, and one on each of three randomly selected week days, corresponding to days and shifts scheduled for angler interviews. All effort counts were recorded on a data form by the pilots. The original study plan called for test netting Lake Charlevoix. However, the creel census information proved to be effective in gathering brown trout strain composition data and was substituted for the proposed test netting.

Results

Determine Return to Creel of Stocked Trout.—A total of 1,809 Lake Charlevoix anglers was interviewed during the expandable creel census of 1996. Total estimated fishing effort for Lake Charlevoix was 79,788 angler hours or 18,509 trips. The brown trout sport harvest estimate was 692 fish, composed of 362 with right ventral clips, 205 with left ventral clips, and 125 with no clip. Scale analysis indicated that all of the no-clip brown trout were of hatchery origin. These fish probably regenerated their clipped fins, or the fin clip was of poor quality when the fish were stocked. The estimated 125 unclipped brown trout were assigned to the other two genetic strains based on the strains' proportion in the sport catch.

Since the numbers of fish stocked of each strain were not equal each year, catch rates were standardized to a stocking rate of 50,000 fish per strain. Catch rates during 1993–96 of the three strains of brown trout indicated that, as in Thunder Bay, the Plymouth Rock strain made the least contribution to the Lake Charlevoix sport catch, while the Wild Rose and Seeforellen strains were better represented (Table 26). In general, the 1992 stockings of Seeforellen and Wild Rose strains produced similar returns of fish in age groups 2 and 3. However, the catch rates of both of these strains declined drastically with subsequent stockings (Table 26).

For the years 1993–95, when no fishing pressure counts were made to determine total angler effort, estimates of brown trout catch by strain can made assuming total fishing effort was similar to 1996 (80,000 angler hours) and utilizing the catch rates (standardized to a stocking rate of 50,000) measured each year. The best fishery occurred during 1993, with an estimated catch of 4,044 brown trout (Table 27). After the 1993 season, the total catch of brown trout declined to 1,025 or less. It is conceivable that the 1993 brown trout catch exceeded 4,044 fish because more angler effort was probably expended on Lake Charlevoix that season due to the good success anglers experienced for brown trout. However, based on these conservative assumptions, return to creel of the 1992 stocking of yearling Wild Rose and Seeforellen brown trout was 4.2% to 3.2%, respectively (Table 28). After the 1992 stockings, the combined return for age-2 and age-3 Wild Rose strain fish from the 1993 and 1994 plants declined to 1.5% and 0.9%, respectively. Similarly, the combined return for age-2 and age-3 Seeforellen strain from the 1994 stocking was less than 0.4%.

Discussion and Management Implications

Our test netting in 1991 revealed that a window of opportunity existed for stocking brown trout when alewives entered Thunder Bay in massive numbers each June to spawn. This alewife migration provided a buffer against predation on stocked brown trout by offering a large supply of prey for piscivorous fish and birds. The brown trout "stocking window" was accordingly changed to mid–June in 1992. Concurrently in 1992, one of the selected strains was introduced to Thunder Bay in a paired planting with Plymouth Rock strain. Harvest of brown trout subsequently rebounded. The recovery was composed of both test strains, although Seeforellen produced far greater returns than Plymouth Rock strain, especially at age three and older. The fact that even Plymouth Rock strain performed reasonably well after 1992 suggests the later stocking window benefited both strains and may have been the chief reason for the recovery of the Thunder Bay brown trout fishery, which was sustained by relatively successful 1991–95 yearling stockings. Unfortunately, the fishery again collapsed following poor performance of subsequent year classes and has failed to recover, despite the implementation of study findings, including the use of Seeforellen strain and the continued adherence to the June stocking window. The decline after 1995 most likely was the result of rising predation on stocked trout, mediated by the decline in alewife numbers and their buffering effect on predation. Harvest the year after stocking was more closely aligned with CPE of alewives in the year of stocking than to number of brown trout stocked. Alewife CPE was low after 1995, as was brown trout harvest (Figure 5). After 1995, the stocking window had essentially closed.

If predation was the cause of the post-1995 decline, it remains unclear what piscivorous species were most important in causing the decline. Walleyes fed regularly on stocked brown trout, but walleye numbers, if anything, declined during the study, based on index netting CPUE. We did not estimate the size of the walleye population and, therefore, cannot estimate how many brown trout would have been consumed by walleyes. The double-crested cormorant population of Thunder Bay, as indexed by three island rookeries (Gull, Scarecrow, and Bird islands), rose from 452 to 3,776 nesting pairs between 1989 and 1997, an 8.4-fold increase (U.S. Fish and Wildlife Service, Shiawassee National Wildlife Refuge, unpublished data). Cormorants have been shown to consume significant numbers of recreational fish, including yellow perch (Belonger 1983; Ross and Johnson 1995; Johnson et al. 1999; VanDeValk et al. 2002), smallmouth bass (Ross and Johnson 1995; Adams et al. 1998; Lantry et al. 1999; Schneider et al. 1999; Schneider and Adams 1999), Atlantic salmon (Cormorant Study Committee 1982), and stocked trout (Wasowicz 1991; Ottenbacher et al. 1994; Ross and Johnson 1995). In most instances, cormorants selected prey fish over game fish (Johnson et al. 1998; Karwowski et al. 1994; Ross and Johnson 1995; Maruca 1997), but in southern Utah, where abundance indices for hatchery-origin rainbow trout in reservoirs were inversely related to cormorant abundance, cormorants appeared to select stocked trout over other species (Ottenbacher et al. 1994). Avian predation at Minersville Reservoir, southern Utah, exceeded angler harvest of put-grow-take rainbow trout (Wasowicz 1991). Predation on game fish rose in Lake Ontario when alewife abundance declined (Ross and Johnson 1995). Thus, the combination of fish predation on stocked trout, rising avian predation, and the sharp decline in alewives, which had been the staple for piscivorous species, may explain the post-1995 decline in brown trout stocking success in Thunder Bay.

Age-1 brown trout did not consume adult alewives in Thunder Bay. Adult alewives were therefore not immediately important to stocked brown trout as food, but only as a buffer against predation. Plankton tows revealed a paucity of zooplankton and ichthyoplankton in Thunder Bay during the spring stocking period. Stomach contents of recently stocked brown trout suggested that during the study period food was rather scarce. Many stomachs were empty and the chief prey of age-1 brown trout was terrestrial insects. Thus, the niche for age-1 brown trout appears fragile: the large population of alewives that had, until 1995 at least, buffered age-1 brown trout from predation, was also probably competing with young brown trout for food. Only after brown trout were large enough to feed on alewives and too large to be consumed by most predators, was their niche relatively secure.

Brief longevity after recruiting to the fishery further reduced the contribution of brown trout to the recreational catch. Overall, during the years 1991–2000, 67% of brown trout in the angler catch were age two, 25% were age three, 6% were age four, and only 1.2% were older than age four. This is similar to the age distribution of the Lake Michigan recreational catch from 1990–99, where 90.4% of the brown trout catch were age three or younger and 2.2% were older than age four (N = 3,339; Michigan Department of Natural Resources, Great Lakes Creel Survey, Federal Aid Study 427, unpublished data). No Plymouth Rock strain brown trout older than age three were observed in the Thunder Bay creel. Thus, even successful year classes of brown trout were rather short-lived in the fishery. A failure of two year-classes in succession, therefore causes collapse of the fishery, as occurred after 1986 and 1996.

Although only one paired comparison was made of Seeforellen and Plymouth Rock strains, Seeforellen returned significantly better, grew faster, and exhibited greater longevity than Plymouth Rock strain in Thunder Bay. Similarly, Plymouth Rock strain produced catch rates less than half those of Seeforellen or Wild Rose strains in Lake Charlevoix. Evidently, Plymouth Rock strain is not well suited to stocking in large lakes. Plymouth Rock strain was the principal strain used for stocking Thunder Bay during 1985–90, which may in part explain the sharp decline in the brown trout fishery from 1986–91.

In general, Seeforellen strain brown trout outperformed the other two strains in Thunder Bay. In both Thunder Bay and Lake Charlevoix, differences in performance between Wild Rose and Seeforellen strains were less pronounced then when compared with Plymouth Rock. In Thunder Bay, however, Seeforellen strain produced significantly better returns to the recreational fishery than Wild Rose in four of eight age-specific comparisons involving four cohort pairs of the two strains. In no case in Thunder Bay did Wild Rose strain produce significantly better returns to the creel than Seeforellen strain.

The test strains were remarkably similar in size and condition when stocked into Thunder Bay; any differences were probably too slight to have affected post-stocking performance. Fin erosion, on the other hand, was common to all test strains. However, in spite of much higher incidence of fin erosion for Seeforellen strain at stocking in the 1992 comparison with Wild Rose strain, Seeforellen returns to creel were significantly higher than Wild Rose strain at both age two and age three. Wild Rose strain was the more affected by both fin erosion and hemorrhaging of the erosion sites in the 1995 paired comparison, which may have contributed to the significantly lower returns of age-2 Wild Rose from the 1995 cohort. Overall, the quality of hatchery products was well controlled and the few differences in quality likely had minimal effect on performance differences of the test strains.

In Thunder Bay, both Wild Rose and Seeforellen strains displayed more rapid growth rates than Plymouth Rock strain. Seeforellen strain grew faster then Wild Rose in some pairings but not in others, while there were no cases of Wild Rose strain reaching significantly larger sizes at age than Seeforellen. The weight–length regressions of Wild Rose and Seeforellen strains were almost identical.

Nuhfer (1996) compared performance of Wild Rose, Seeforellen, and Plymouth Rock strains in small inland lakes where piscine predators were scarce. As with our study, he found that Wild Rose and Seeforellen strains grew faster than Plymouth Rock strain. Unlike Thunder Bay, survival of Plymouth Rock strain was higher than Wild Rose and Seeforellen strains. Nuhfer (1996) suggested the scarcity of piscivores in his test lakes may have contributed to the survival patterns noted in his study. Had predators been more abundant in Nuhfer's study, the slower growing Plymouth Rock strain might have experienced lower survival due to the longer period of time they were of sizes most vulnerable to predation.

All brown trout for the Thunder Bay portion of the strain evaluation study were stocked off our research vessel approximately 3 km from shore. The purpose of offshore stocking was to place the fish in an offshore environment where test netting had shown few piscivorous fish were present. The comparison of boat- versus shore-stocking methods, however, suggested there was no measurable advantage to offshore stocking. This element of the study was compromised by low sample sizes of the test groups obtained from the creel survey in those years. Clearly, at least during the conditions that prevailed after 1995 in Thunder Bay, survival of stocked brown trout was uniformly low (Table 15) and stocking brown trout 3 km offshore was not an effective remedy.

Even during the peak years of survival (1992–95), percent return of stocked brown trout during the study period fell far below 10%, the level in the 1970s when a good Thunder Bay fishery was produced. It appears highly unlikely that present or future environmental conditions will allow returns as high as 5%. Under conditions prevailing at the end of the study, returns were regularly below 1% of the number stocked and biomass of each year class harvested was less than the annual biomass of yearlings stocked.

Michigan's Fish Stocking Guidelines (Dexter and O'Neil 2004) estimate the cost of rearing salmonid yearlings in the State hatchery system to be $730.00 per 1,000 fish. The Guidelines suggest that 29 angler trips should be generated for each 1,000 yearling salmonids stocked. During the Thunder Bay study, stockings ranged near 120,000 yearlings per year at an estimated annual cost of $87,600. To meet criteria of the Stocking Guidelines, these stockings should have generated 3,480 angler trips. Brown trout harvest during 1995–2000 averaged 1,202 during the period. Angler use during 1995–2000 averaged 24,000 trips per year at Alpena and these trips accounted for a combined average annual harvest of 13,304 Chinook salmon, lake trout, and steelhead trout. Brown trout accounted for 8.2% of the average annual harvest. If fishing trips are proportional to harvest, brown trout stimulated 8.2% of the angler days fished out of Alpena during 1995–2000, or 1,968 of the 24,000 trips. The brown trout fishery therefore stimulated an average of only 57% of the 3,480 angler trips required to meet standards of the Michigan Fish Stocking Guidelines. Thus, as measured against these standards, (percent of number stocked, percent of biomass stocked, and angler trips generated) returns of brown trout stocked in Thunder Bay after 1995 were below the level of an economically viable put-grow-take stocking program.

Acknowledgements

The late John Weber collected harvest data for Thunder Bay from 1970 through 1985 and was the inspiration for this study. Fran Rose collected almost all the harvest data and biological data from creeled brown trout for this study. The staff of Oden State Fish Hatchery delivered the three test strains in near identical numbers, size, and condition. The crew of the Research Vessel *Chinook* stocked the fish and conducted most of the index netting. Brian Hoxie assisted with index netting. Thanks go to Mr. James O'Neil for allowing us to use his property for shore stocking during the offshore/nearshore stocking method comparison. Chris Geddes (Great Lakes GIS project) assisted with mapping, and Deborah MacConnell formatted the manuscript. James Schneider provided a thorough and helpful editorial review. David Borgeson, Jr. also reviewed the manuscript. This research was supported, in part, with funds from the Federal Aid in Sport Fish Restoration Act (Project F-80-R, Study 230469, Michigan).

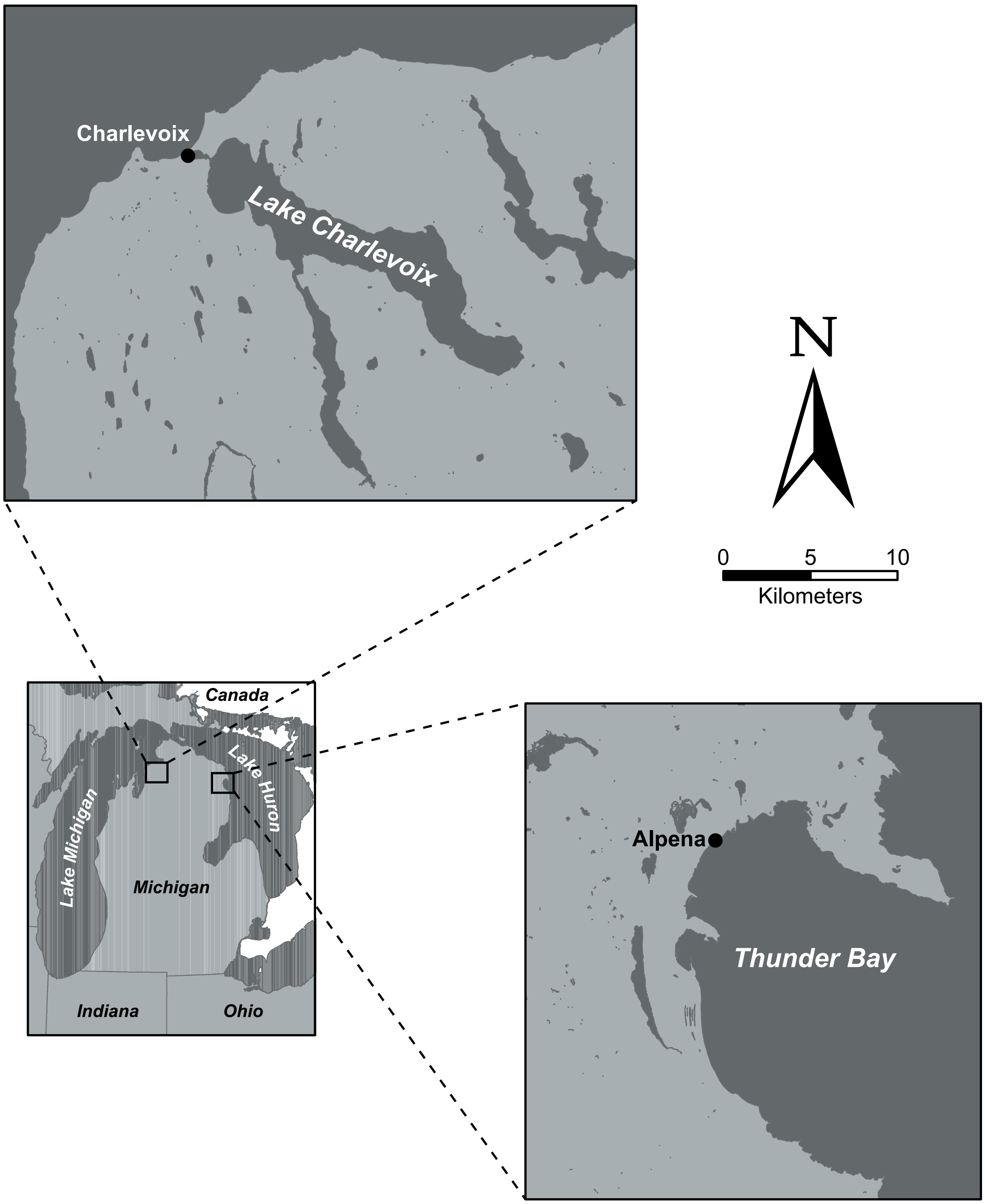

Figure 1.−Map of study area, including Lake Charlevoix and Thunder Bay, Michigan.

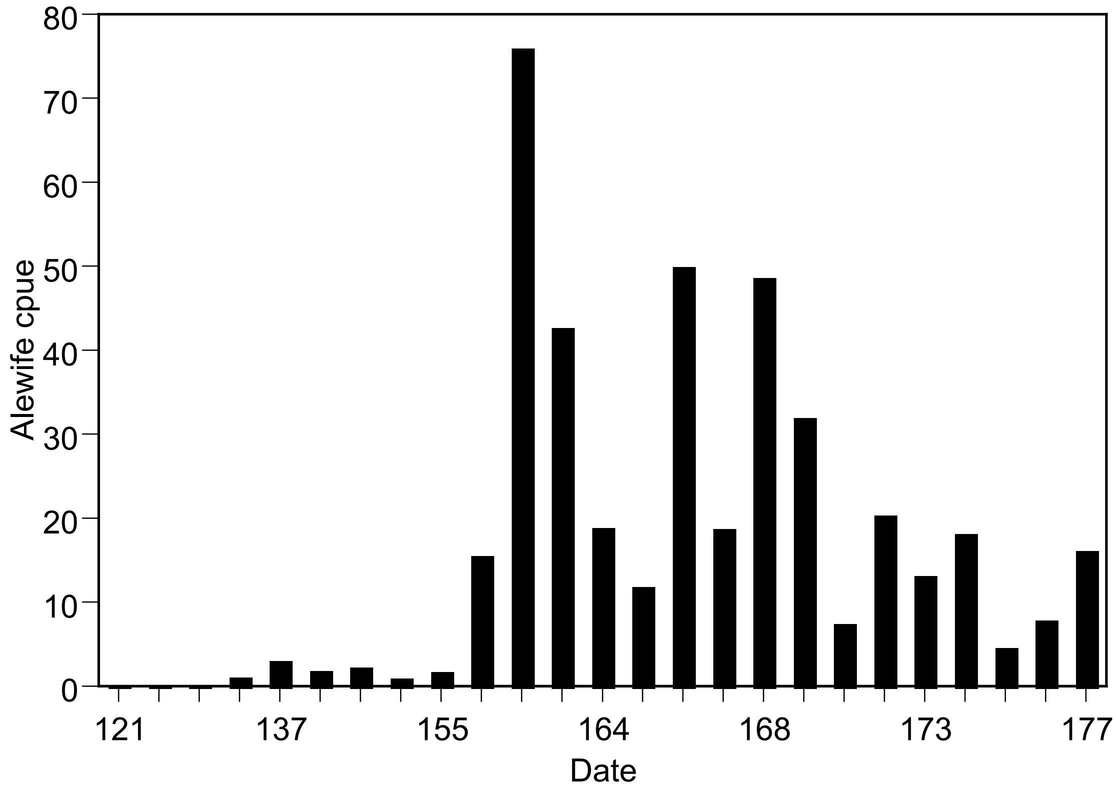

Figure 2.−Alewife catch per 30 m of gillnet (CPUE) in spring surveys, mean day of year, 1990–2001, Thunder Bay.

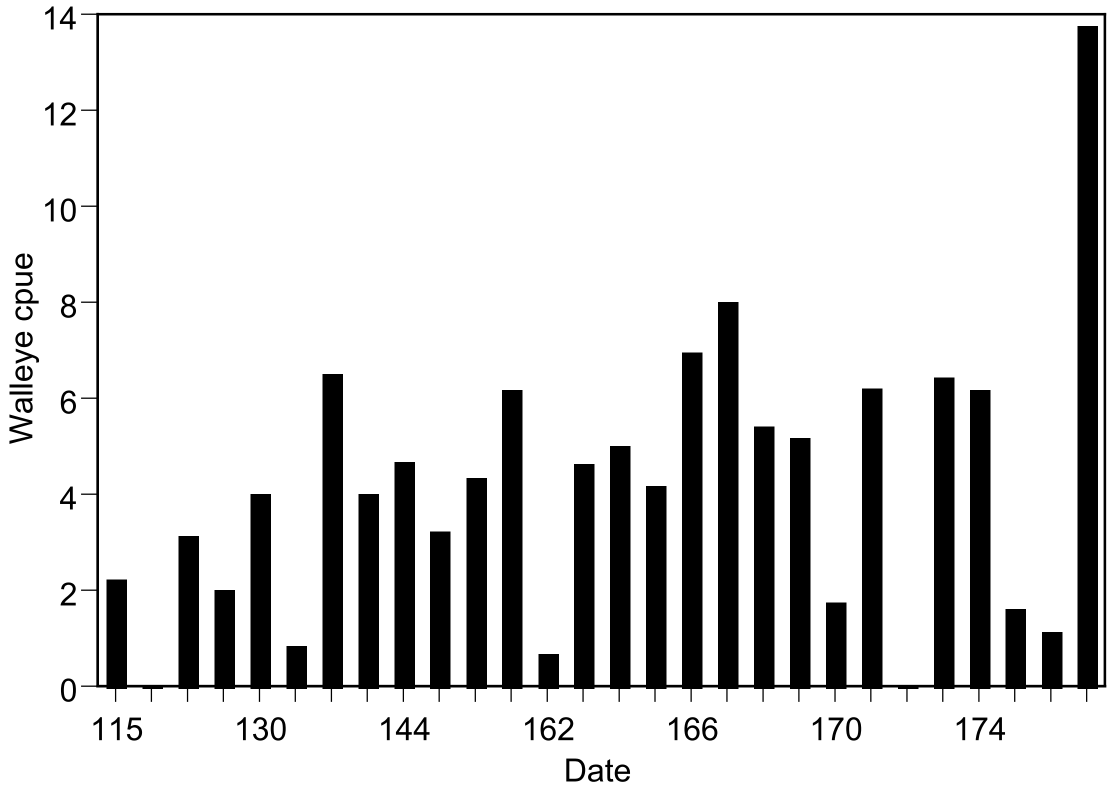

Figure 3.−Walleye catch per 76 m (CPUE) of gillnet in spring surveys, by mean day of year, Thunder Bay, 1991–2001.

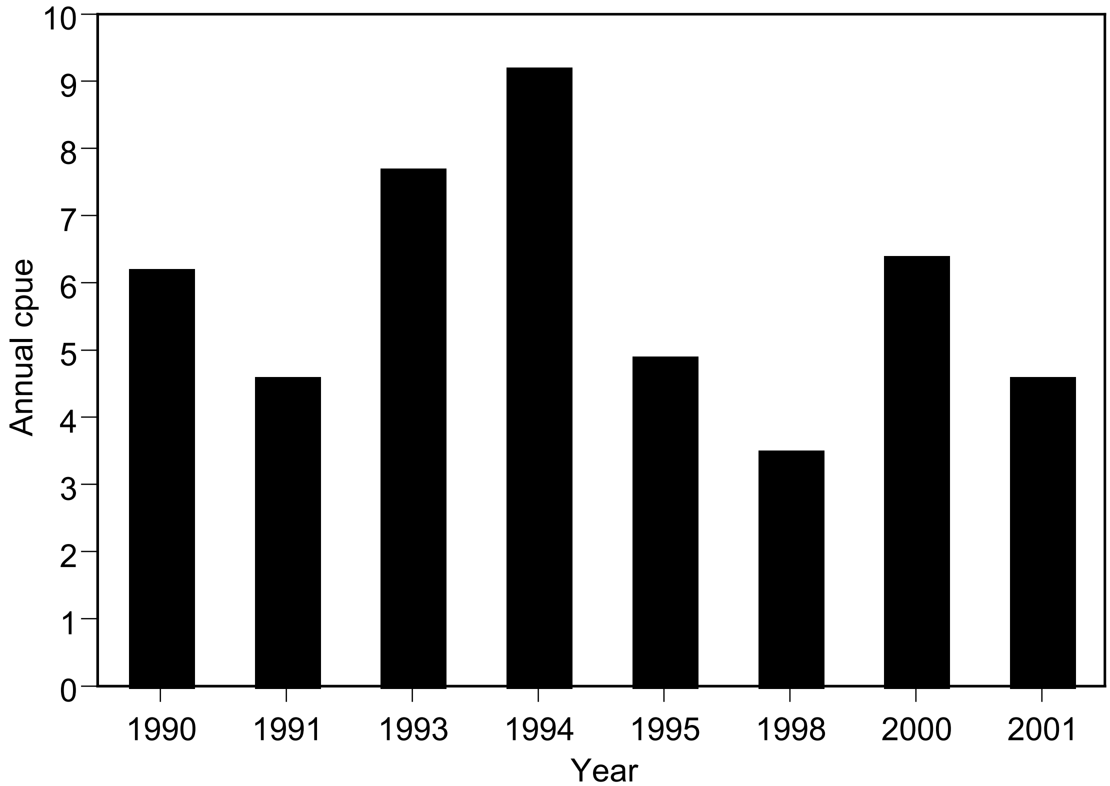

Figure 4.−Mean annual walleye catch per 76 m (CPUE) in gillnets, Thunder Bay, 1990–2001.

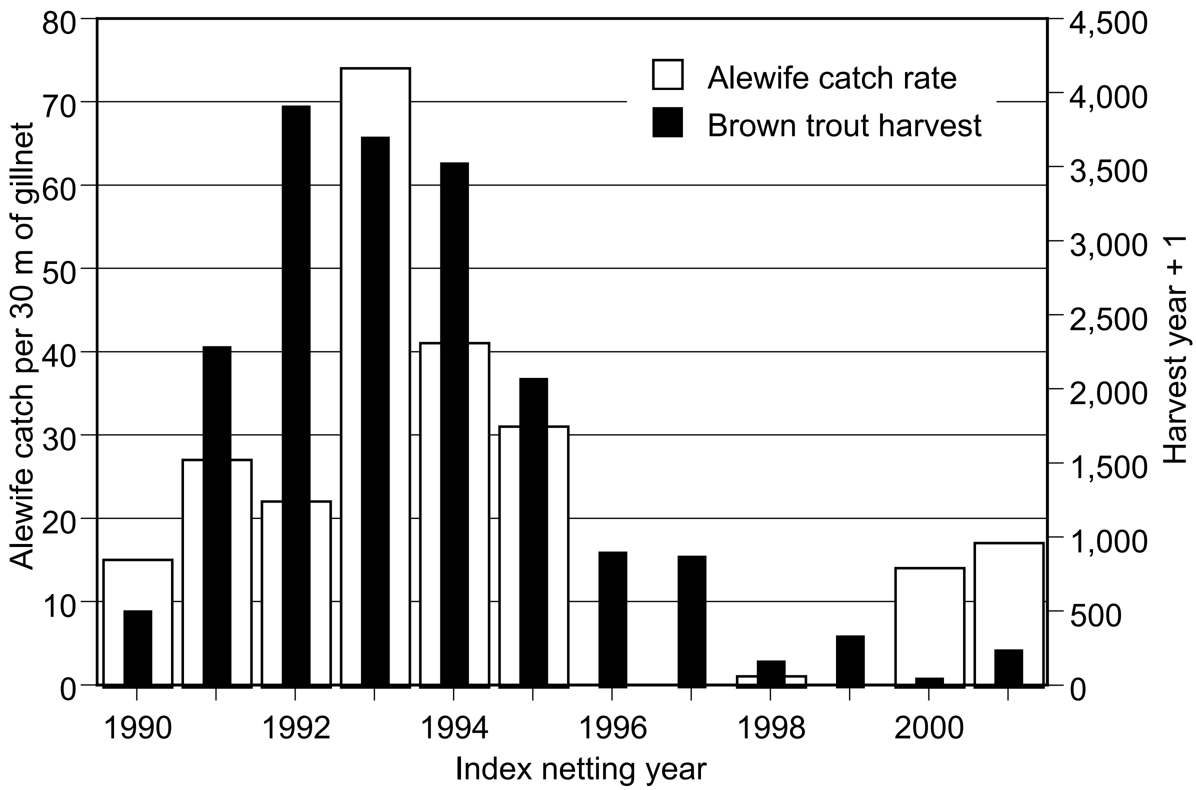

Figure 5.−Mean annual alewife CPUE in small-mesh gillnets compared with brown trout harvest in netting year +1. Alewife index data lacking for 1996, 1997, and 1999.

Table 1.–Fish species sampled in graded-mesh gill nets, spring, 1990–2001, Thunder Bay, Lake Huron.

Common name	Scientific name	Frequency	Mean total length (mm)	Percent
Alewife	*Alosa pseudoharengus*	971	171	30.30
Walleye	*Sander vitreus*	750	492	23.40
Yearling brown trout	*Salmo trutta*	734	198	22.90
Channel catfish	*Ictalurus punctatus*	245	432	7.64
White sucker	*Catostomus commersoni*	100	403	3.12
Freshwater drum	*Aplodinotus grunniens*	73	362	2.28
Burbot	*Lota lota*	63	568	1.97
Age 2+ brown trout	*Salmo trutta*	62	468	1.93
Gizzard shad	*Dorsoma cepedianum*	57	390	1.78
Lake trout	*Salvelinus namaycush*	45	569	1.40
Brown bullhead	*Ameiurus nebulosus*	22	295	0.69
Round whitefish	*Prosopium cylindraceum*	20	447	0.62
Yellow perch	*Perca flavescens*	14	208	0.44
Rock bass	*Ambloplites rupestris*	11	164	0.34
Common carp	*Cyprinus carpio*	9	631	0.28
Northern pike	*Esox lucius*	7	726	0.22
Bowfin	*Amia calva*	4	632	0.12
Rainbow trout	*Oncorhynchus mykiss*	4	469	0.12
Smallmouth bass	*Micropterus dolomieu*	3	291	0.09
Stonecat	*Noturus flavus*	2	214	0.06
Chinook salmon	*Oncorhynchus tshawytscha*	2	439	0.06
Longnose sucker	*Catostomus catostomus*	2	463	0.06
Longnose gar	*Lepisosteus osseus*	1	713	0.03
White perch	*Morone americana*	1	198	0.03
Lake whitefish	*Coregonus clupeaformis*	1	555	0.03
Largemouth bass	*Micropterus salmoides*	1	314	0.03
Round goby	*Neogobius melanostomus*	1	132	0.03
Rainbow smelt	*Osmerus mordax*	0	–	–
Sea lamprey	*Petromyzon marinus*	0	–	–
Total		3,205		100

Table 2.–Number of yearling brown trout stocked and estimated harvest, 1970–2002, Thunder Bay, Lake Huron.

Year	Harvest	Effort (angler hr X 1000)	CPE (catch per angler hr)	Comments	Yearling brown trout stocked
1970	0	–	–	Weber 1988	25,065
1971	200	–	–	Weber 1988	109,291
1972	150	–	–	Weber 1988	70,000
1973	900	–	–	Weber 1988	120,000
1974	7,000	–	–	Weber 1988	57,000
1975	7,330	116.8	0.063	Weber 1988	60,000
1976	3,715	66.6	0.056	Weber 1988	75,000
1977	4,655	81.3	0.057	Weber 1988	75,000
1978	3,504	46.4	0.076	Weber 1988	32,000
1979	400	35.0	0.011	Weber 1988	25,000
1980	400	35.0	0.011	Based on partial census, Weber 1988	25,000
1981	400	35.0	0.011	Based on partial census, Weber 1988	25,000
1982	400	35.0	0.011	Based on partial census, Weber 1988	0
1983	400	35.0	0.011	Based on partial census, Weber 1988	100,000
1984	400	35.0	0.011	Based on partial census, Weber 1988	99,781
1985	1,803	50.4	0.036	Weber 1988	75,000
1986	3,873	56.5	0.068	MIDNR, Federal Aid Study 427	102,973
1987	3,107	72.3	0.043	MIDNR, Federal Aid Study 427	73,567
1988	656	69.6	0.009	MIDNR, Federal Aid Study 427	100,273
1989		–	–	No data	100,000
1990	260	–	–	Harvest indexed from charter reports	95,032
1991	500	58.2	0.007	MIDNR, Federal Aid Study 427	118,202
1992	2,284	79.9	0.025	MIDNR, Federal Aid Study 427	109,968
1993	3,908	89.6	0.038	MIDNR, Federal Aid Study 427	113,133
1994	3,698	108.8	0.031	MIDNR, Federal Aid Study 427	125,864
1995	3,524	143.3	0.022	MIDNR, Federal Aid Study 427	114,488
1996	2,069	135.6	0.014	MIDNR, Federal Aid Study 427	89,832
1997	896	112.7	0.008	MIDNR, Federal Aid Study 427	120,270
1998	869	79.1	0.010	MIDNR, Federal Aid Study 427	126,595
1999	161	52.3	0.003	MIDNR, Federal Aid Study 427	110,411
2000	330	65.4	0.005	MIDNR, Federal Aid Study 427	28,043
2001	56	40.8	0.001	MIDNR, Federal Aid Study 427	108,384
2002	277	45.2	0.005	MIDNR, Federal Aid Study 427	102,281

Table 3.–Number of each test strain stocked, adjusted for fin clip quality, Thunder Bay, 1991–95.

Year	Strain	Clip	Mark adjustment factor	Number stocked	Number with detectable mark
1991	Seeforellen	RV	100.0	59,288	59,288
	Plymouth Rock	LV	100.0	58,914	58,914
1992	Seeforellen	RV	81.5	54,917	44,757
	Wild Rose	LV	84.5	55,051	46,518
1993	Seeforellen	RV	99.3	56,133	55,740
	Wild Rose	LV	91.0	57,000	51,870
1994	Seeforellen	RV	97.4	62,932	61,296
	Wild Rose	LV	95.5	62,932	60,100
1995	Seeforellen	RV	98.6	58,098	57,285
	Wild Rose	LV	94.6	56,390	53,345

Table 4.–Number of each test strain stocked in Lake Charlevoix, 1991–95.

	Stocking Year				
Strain	1991	1992	1993	1994	1995
Seeforellen	39,600	19,500	–	45,135	39,988
Plymouth Rock	39,800	–	39,992	–	–
Wild Rose	–	46,400	33,786	45,100	39,980
Total	79,400	65,900	73,778	90,235	79,968

Table 5.–Number of brown trout stocked in boat-shore stocking site comparison at Thunder Bay, 1996–97.

Year	Offshore	Beach	Total
1996	42,268	47,564	89,832
1997	61,601	58,669	120,270

Table 6.–Summary of size and condition at stocking of test strains stocked in Thunder Bay, 1991–95.

Year	Strain	Statistic	Length (mm)	Weight (gm)	KTL[a]	VFI[b]
1991	Plymouth Rock	Mean	174	89	1.084[c]	4.0[c]
		S D	17	17	0.067	0.067
		N	99	99	99	59
	Seeforellen	Mean	178	58	1.009[c]	3.4[c]
		S D	18	16	0.086	0.6
		N	100	100	100	60
1992	Wild Rose	Mean	179	66[c]	1.141[c]	3.1
		S D	13	16	0.091	0.5
		N	40	40	40	40
	Seeforellen	Mean	177	57[c]	0.993[c]	3.2
		S D	20	21	0.099	0.6
		N	40	40	40	40
1993	Wild Rose	Mean	200	95[3]	1.058[c]	3.3
		S D	20	30	0.088	0.5
		N	82	40	40	60
	Seeforellen	Mean	201	82[c]	0.966[c]	3.3
		S D	22	27	0.084	0.5
		N	82	82	82	82
1994	Wild Rose	Mean	179	61	1.035[c]	2.6[c]
		S D	17	18	0.128	0.5
		N	60	60	60	60
	Seeforellen	Mean	181	66	1.077[c]	3.5[c]
		S D	20	20	0.087	0.5
		N	60	60	60	60
1995	Wild Rose	Mean	205[c]	101[c]	1.136[c]	3.8[c]
		S D	17	31	0.128	0.5
		N	60	60	60	60
	Seeforellen	Mean	198[c]	84[c]	1.055[c]	4.0[c]
		S D	15	20	0.066	0.0
		N	41	41	41	41

[a] Condition factor: KTL = Weight (gm)/Length (mm)^3 x 10^5
[b] Visceral Fat Index
[c] Significant difference between strains (t-test, $P \leq 0.05$).

Table 7.–Total length and fin clip quality, test strains stocked in Thunder Bay, 1991–95.

Year and strain	June stocking dates	Sample size	Average total length (mm)	Standard deviation	Mark quality (percent)[a]			
					Good	Fair	Poor	Wrong fin
1991								
Seeforellen	17–18	143	187.1[b]	19.6	84.6	15.4	0.0	0.0
Plymouth Rock	18–19	137	179.8[b]	18.3	94.2	5.8	0.0	0.0
1992								
Seeforellen	8–9	130	184.2	20.8	67.7	13.8	18.5	0.0
Wild Rose	9–10	168	179.3	19.3	59.5	25.0	14.9	0.6
1993								
Seeforellen	14–15	149	201.2	20.9	95.8	3.5	0.7	0
Wild Rose	16–17	177	199.7	18.9	69.5	21.5	8.5	0.5
1994								
Seeforellen	14	186	178.0	18.2	95.2	2.2	2.2	0.0
Wild Rose	13	202	180.0	17.5	87.1	8.4	4.5	0.0
1995								
Seeforellen	12–14	152	198.0[b]	15.0	94.7	3.9	1.3	0.0
Wild Rose	12–14	147	207.0[b]	19.0	76.9	17.7	5.4	0.0

[a] Good = no regeneration
Fair = recognizable clip but with regeneration
Poor = no recognizable clip or clip likely to completely regenerate

[b] Significant difference between strains ($P \leq 0.05$).

Table 8.–Fin erosion indices (%) for test strains at time of stocking, 1992–95 (no data for 1991).

Year	Strain	Sample size	No active fin erosion	Active erosion (frayed fins)	Erosion with bleeding	Erosion with secondary infection
1992	Wild Rose	40	70	18	12	0
	Seeforellen	40	33	67	0	0
1993	Wild Rose	82	55	27	18	0
	Seeforellen	82	52	46	1	0
1994	Wild Rose	60	60	25	15	0
	Seeforellen	60	98	2	0	0
1995	Wild Rose	60	37	33	30	0
	Seeforellen	41	73	22	5	0

Table 9.–Identifiable prey consumed by predator fish, Thunder Bay, spring 1990.

			Prey consumed							
Predator species	Sample size	Average total length (mm)	Brown trout	Alewife	Smelt	Nine-spine stickleback	Trout perch	White sucker	Crayfish[a]	Other[b]
Lake trout	20	570	0	2	109	0	0	0	0	0
Brown trout	36	331	4	7	6	0	1	0	1	5
Rainbow trout	1	250	(void)	0	0	0	0	0	0	0
Chinook salmon	1	310	(void)	0	0	0	0	0	0	0
Walleye	124	531	10	85	27	0	0	0	0	0
Burbot	28	606	1	27	9	12	1	1	40	0
Channel catfish	42	435	1	0	1	0	0	0	24	11
Northern pike	2	784	(void)	0	0	0	0	0	0	0

[a] *Orconectes virilis*
[b] Amphipods and insects, expressed as number of fish in which observed.

Table 10.–Identifiable prey from stomachs of piscivorous fish sampled from Thunder Bay, by sampling period, spring 1990.

Sampling period	Number stomachs	Percent void	Prey consumed							
			Brown trout	Alewife	Smelt	Nine-spine stickleback	Trout perch	White sucker	Crayfish[a]	Other[b]
May 1–7										
Number	43	65.0	0	0	52	0	0	1	4	0
Percent of fish/crayfish consumed			0.0	0.0	91.2	0.0	0.0	1.8	7.0	–
May 10–17										
Number	103	40.8	16	36	39	1	5	0	44	16
Percent of fish/crayfish consumed			11.3	25.5	27.7	0.7	3.5	0.0	31.2	–
May 23–June 6										
Number	108	28.7	0	97	6	11	0	0	16	0
Percent of fish/crayfish consumed			0.0	74.6	4.6	8.5	0.0	0.0	12.3	–

[a] *Orconectes virilis*
[b] Amphipods and insects, expressed as number of fish in which observed.

Table 11.–Diets of predator fish taken in spring gill net assessments, Thunder Bay, June 1993–95.

			Number of stomachs containing food items (number of items consumed in parentheses)				
Predator species	Number examined	Void	Insects	Crayfish	Alewife	Brown trout	Unidentified fish
1993							
Walleye	48	26	0	0	20 (41)	3 (4)	1 (1)
Adult brown trout	6	2	0	0	2 (7)	0	3 (4)
Burbot	2	0	0	0	0	0	2 (7)
1994							
Walleye	80	35	0	0	38 (134)	2 (4)	13 (20)
Adult brown trout	4	2	0	0	6 (12)	0	2 (2)
Burbot	2	1	0	0	1 (2)	0	1 (2)
Channel catfish	2	0	1 (1)	1 (1)	1 (1)	0	2 (5)
1995							
Walleye	40	27	0	0	9(17)	1(5)	3(3)
Adult brown trout	2	0	1(27)	0	1(3)	0	1(1)

Table 12.–Catch of planktonic organisms >1.0 mm in body length in three 10-min 1.5-meter plankton net tows, Thunder Bay, 1990.

Date	Depth strata (m)	Catostomidae	Osmeridae	Percidae	Coregonus sp.	Cladocera	Copopoda	Chironomidae	Amphipoda	Hydracarina	Corixidae
25 May	1.5	1						2		9	
	3				2			2	1	1	
	5		7	3		1		1		11	1
06 Jun	1.5		1	1							
	3		3		2						
	5		3		1			3			
21 Jun	1.5		1								
	3		2								2
	5		1								
06 Jul	1.5				No catch >1 mm body length in 3, 10-min tows at 1.5 m						
	3		2	1							
	5		3					9		2	1

Table 13.–Diet of recently stocked brown trout during June and July, Thunder Bay, 1990–98.

Stomach contents	Number of stomachs with item	Food item consumed	
		Number	Percent
Overall			
Nothing	354	–	–
% nothing	73%	–	–
Food	128	–	–
Item			
Vegetation	3	–	–
Amphipods	2	2	0.2
Crayfish	1	1	0.1
Diptera, aquatic	3	6	0.7
Hexagenia sp	8	115	13.8
Damsel flies	1	4	0.5
Zebra mussel	1	1	0.1
Snails	8	35	4.2
Unidentified terrestrial insects	54	188	22.5
Ants	27	274	32.8
Caddis fly larvae/pupae	1	1	0.1
Other invertebrates	20	123	14.7
Alewife	8	8	1.0
Nine-spine stickleback	16	30	3.6
Johnny darter	1	1	0.1
Slimy sculpin	1	1	0.1
Unidentified fish	8	9	1.1
Unidentifiable	33	36	4.3

Table 14.–Brown trout observed in creel (not expanded to recreational fishing effort), Michigan waters of Lake Huron, by strain and year stocked (cohort), 1991–99.

Age	Count by strain			Observed return per 60,000 stocked		
	Seeforellen	Wild Rose	Plymouth Rock	Seeforellen	Wild Rose	Plymouth Rock
			1991 cohort			
1	0	–	0	0.0	–	0.0
2	126	–	111	127.5	–	113.0
3	58	–	21	58.7	–	21.4
4	1	–	0	1.0	–	0.0
5	1	–	0	1.0	–	0.0
6	0	–	0	0.0	–	0.0
7	0	–	0	0.0	–	0.0
Total	186	–	132	188.2		134.4
			1992 cohort			
1	8	3	–	8.7	3.3	–
2	218	166	–	238.2	180.9	–
3	35	25	–	38.2	27.2	–
4	17	3	–	18.6	3.3	–
5	1	0	–	1.1	0.0	–
6	0	0	–	0.0	0.0	–
7	0	0	–	0.0	0.0	–
Total	279	197		304.8	214.7	
			1993 cohort			
1	2	4	–	2.1	4.2	–
2	91	98	–	97.3	103.2	–
3	49	61	–	52.4	64.2	–
4	20	2	–	21.4	2.1	–
5	2	4	–	2.1	4.2	–
6	0	0	–	0.0	0.0	–
7	0	1	–	0.0	1.1	–
Total	164	170		175.3	179.0	
			1994 cohort			
1	0	4	–	0.0	3.8	–
2	115	114	–	109.6	108.7	–
3	42	20	–	40.0	19.1	–
4	21	17	–	20.0	16.2	–
5	2	4	–	1.9	3.8	–
6	0	0	–	0.0	0.0	–
Total	180	159		171.5	151.6	
			1995 cohort			
1	1	0	–	1.0	0.0	–
2	156	56	–	161.1	59.6	–
3	54	45	–	55.8	47.9	–
4	4	9	–	4.1	9.6	–
5	2	0	–	2.1	0.0	–
Total	217	110		224.1	117.1	

Table 15.–Brown trout observed in creel (not expanded to recreational fishing effort), Michigan waters of Lake Huron, by stocking method (boat versus shore) and year stocked (cohort), 1996–99.

		Count by strain		Observed return per 60,000 stocked	
Cohort	Age	Boat	Shore	Boat	Shore
1996	1	1	0	1.42	0.00
	2	9	6	12.78	7.57
	3	5	9	7.10	11.35
	4	1	4	1.42	5.05
Total		16	19	22.72	23.97
1997	1	0	0	0.00	0.00
	2	13	14	12.66	14.32
	3	1	4	0.97	4.09
Total		14	18	13.63	18.41

Table 16.–Binomial tests of age-specific returns (observed by creel census clerks) from paired stockings to compare strains and stocking method, Michigan ports on Lake Huron, 1992–99.

Test group	Stocking year	Age	Number observed	Observed proportions	Expected proportions	Two-tailed significance (Z approx.)
Seeforellen	1991	2	126	0.502	0.532	
Plymouth Rock			111	0.498	0.468	0.396
Seeforellen	1991	3+	60	0.741	0.532	
Plymouth Rock			21	0.259	0.468	0.001[a]
Seeforellen	1992	2	218	0.568	0.499	
Wild Rose			166	0.432	0.501	0.008[a]
Seeforellen	1992	3+	53	0.654	0.499	
Wild Rose			28	0.346	0.501	0.008[a]
Seeforellen	1993	2	91	0.481	0.496	
Wild Rose			98	0.519	0.504	0.744
Seeforellen	1993	3+	71	0.511	0.496	
Wild Rose			68	0.489	0.504	0.792
Seeforellen	1994	2	115	0.502	0.500	
Wild Rose			114	0.498	0.500	1.000
Seeforellen	1994	3+	65	0.613	0.500	
Wild Rose			41	0.387	0.500	0.026[a]
Seeforellen	1995	2	156	0.736	0.507	
Wild Rose			56	0.264	0.493	<0.001[a]
Seeforellen	1995	3+	60	0.526	0.507	
Wild Rose			54	0.474	0.493	0.750
Boat	1996 &	2+	29	0.433	0.494	
Shore	1997		38	0.567	0.506	0.28

[a] Significant difference ($P \leq 0.05$) between test groups.

Table 17.–Number of each strain examined during Alpena Brown Trout Festival, 1993–98.

Strain	1993	1994	1995	1996	1997	1998
Seeforellen	203[a]	89[a]	59	93[a]	–	–
Wild Rose or Plymouth Rock	113[a]	56[a]	70	50[a]	–	–
Unknown	218	146	235	69	202	155
Total	534	291	364	212	202	155

[a] Ratio of test strains (binomial test) significantly different from 0.50 ($P < 0.01$). Numbers stocked were essentially the same for each paired comparison (Table 1.)

Table 18.–Number of each test group observed, per 60,000 stocked, by creel census clerks at 10 Lake Huron sites, 1991–99.

	Test group				
	Seeforellen	Wild Rose	Plymouth Rock	Boat	Shore
Rogers City	0.62	0.00	0.00	0.00	0.00
Rockport	3.91	1.30	1.02	2.31	0.57
Alpena	195.84	160.00	131.38	17.91	12.99
Harrisville	4.53	0.52	0.00	0.58	1.69
Oscoda	3.50	1.56	1.02	1.16	1.69
Tawas	1.44	0.26	1.02	0.00	0.00
Pt. Austin	0.21	0.00	0.00	0.00	0.00
Harbor Beach	0.41	0.52	0.00	0.00	0.00
Pt. Sanilac	0.41	0.26	0.00	0.00	0.00
Lexington	0.41	0.86	0.00	0.00	0.00
Total	211.28	165.27	134.43	21.95	16.94

Table 19.–Mean lengths and weights at age by strain, cohort, and age, of brown trout observed in recreational catch, Lake Huron.

Stocking year	Strain	Age	Sample size	Mean total length (mm)	Mean weight (g)
1991	Plymouth Rock	2	111	413[a]	985[a]
	Seeforellen	2	127	498[a]	1,892[a]
	Plymouth Rock	3	21	571[a]	2,564[a]
	Seeforellen	3	58	705[a]	5,562[a]
1992	Wild Rose	2	166	492[a]	1,721[a]
	Seeforellen	2	219	519[a]	2,041[a]
	Wild Rose	3	25	621	3,386
	Seeforellen	3	35	641	3,451
1993	Wild Rose	2	98	476	1,614
	Seeforellen	2	90	493	1,617
	Wild Rose	3	60	595[a]	3,194[a]
	Seeforellen	3	49	678[a]	4,725[a]
1994	Wild Rose	2	114	478	1,691
	Seeforellen	2	115	484	1,528
	Wild Rose	3	20	584[a]	2,901
	Seeforellen	3	42	635[a]	3,515
	Wild Rose	4	17	654[a]	4,325
	Seeforellen	4	21	708[a]	4,821
1995	Wild Rose	2	56	467	1,641
	Seeforellen	2	156	461	1,433
	Wild Rose	3	45	592[a]	3,156[a]
	Seeforellen	3	53	629[a]	3,831[a]
	Wild Rose	4	9	548[a]	2,394[a]
	Seeforellen	4	4	715[a]	5,613[a]

[a] Significant difference between strains ($P \leq 0.05$).

Table 20.–Weight (gm)–length (mm) equations from comparisons of Seeforellen with Plymouth Rock and Seeforellen with Wild Rose strains of brown trout, 1991–95 stocking cohorts, from recreational catch, Lake Huron.

		Power equation				Comparison of slopes, linear regression		
Cohorts	Strains	Degrees of freedom	R^2	Intercept	Power exponent/ linear slope	Residual sum of squares	t	Significance of difference
1991	Seeforellen	182	0.956	2.7×10^{-6}	3.2656	4.42		
	Plymouth Rock	130	0.941	1.3×10^{-6}	3.3736	3.37	1.2125	= 0.2
1992–95	Seeforellen	830	0.948	2.3×10^{-6}	3.2795	42.84		
	Wild Rose	630	0.915	2.8×10^{-6}	3.2708	16.86	0.1453	> 0.9

Table 21.–Comparison of lengths and weights of brown trout by year, strain, and age from Alpena Brown Trout Festival, mid-July 1993–96.

	1993		1994		1995			1996	
Parameters	Age 2	Age 3	Age 2	Age 3	Age 2	Age 3	Age 4	Age 2	Age 3
Seeforellen									
Length (mm)	518	670	528	690[a]	519[a]	701[a]	721	532[a]	711[a]
Standard deviation	42	49	46	59	46	51	41	35	47
Weight (kg)	2.01	4.93	2.11	5.07[a]	2.06	5.42[a]	5.50	2.33	5.85[a]
Standard deviation	0.6	1.23	0.71	1.21	0.60	1.00	0.81	0.49	1.57
Number	26	12	61	46	37	25	7	29	7
Wild Rose									
Length (mm)	521	–	513	628[a]	500[a]	6.15[a]	665	504[a]	586[a]
Standard deviation	36	–	47	36	26	52	–	22	39
Weight (kg)	2.22	–	2.15	3.79[a]	2.04	3.78[a]	4.31	2.16	3.51[a]
Standard deviation	1.04	–	0.79	0.67	0.39	0.97	–	0.31	0.85
Number	27	–	37	9	50	26	1		
Plymouth Rock									
Length (mm)	–	605	–	–	–	–	–	–	–
Standard deviation	–	17.7	–	–	–	–	–	–	–
Weight (kg)	–	3.76	–	–	–	–	–	–	–
Standard deviation	–	0.23	–	–	–	–	–	–	–
Number	0	2	0	0	0	0	0	0	0

[a] Significant difference (t-test: $P < 0.05$) between Wild Rose and Seeforellen.

Table 22.–Stomach contents of brown trout examined during Brown Trout Festivals of 1993–96, Thunder Bay, Lake Huron.

			Number of prey items observed							
Age	Fish examined	Void stomachs	Unidentified fish	Crayfish	Alewife	Smelt	Nine-spine stickleback	Sculpin	Lake whitefish	Trout perch
Seeforellen										
2	150	55	66	0	85	8	12	2	1	0
3	96	38	30	0	72	2	3	2	0	0
Wild rose										
2	128	45	47	2	85	5	10	2	0	4
3	39	18	18	0	22	3	1	0	0	1

Table 23.–Maturity rates for three strains of brown trout (sexes combined) in July during Alpena Brown Trout Festival, Thunder Bay, Lake Huron.

Age and maturity	Seeforellen	Wild Rose	Plymouth Rock
	1993 festival		
Age 2			
Number immature	8	3	–
Number mature	18	23	–
Percent mature	69.2	88.5	–
Age 3			
Number immature	1	–	0
Number mature	10	–	2
Percent mature	90.9	–	100.0
	1994 festival		
Age 2			
Number immature	15	6	–
Number mature	46	32	–
Percent mature	61.0	84.2	–
Age 3			
Number immature	1	0	–
Number mature	46	9	–
Percent mature	97.9	100.0	–
	1995 festival		
Age 2			
Number immature	12	6	–
Number mature	23	44	–
Percent mature	66.0	88.0	–
Age 3			
Number immature	1	1	–
Number mature	23	25	–
Percent mature	96.0	96.0	–
Age 4			
Number immature	0	0	–
Number mature	8	1	–
Percent mature	100.0	100.0	–
	1996 festival		
Age 2			
Number immature	11	4	–
Number mature	18	14	–
Percent mature	62.0	78.0	–
Age 3			
Number immature	0	0	–
Number mature	7	5	–
Percent mature	100.0	100.0	–

Table 24.–Lengths, weights, and visceral fat index for male brown trout, by strain, sampled during fall surveys of Thunder Bay, Lake Huron, 1993–95.

	Seeforellen				Wild Rose			Plymouth Rock
	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 3
Number mature	19	56	15	1	2	27	2	0
Number immature	0	1	0	0	0	1	0	0
Mean total length (mm)	376	583[a]	726	711	440	548[a]	636	–
Standard deviation	52	78	40	–	105	40	39	–
Mean weight (kg)	0.73	2.70[a]	5.11	5.16	1.46	2.34[a]	3.71	–
Standard deviation	0.32	1.10	1.05	–	1.1	0.52	1.10	–
Visceral fat index	2.3	1.2	1.3	0.0	1.0	1.6	1.5	–
Standard deviation	1.4	1.1	0.9	–	1.4	1.0	2.1	–

[a] Significant difference between strains within age group (t test, P<0.05).

Table 25.–Lengths, weights, and visceral fat and gonadal somatic indices for female brown trout, by strain, sampled during fall surveys of Thunder Bay, Lake Huron, 1993–95.

	Seeforellen				Wild Rose				Plymouth Rock
	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4	Age 3
Number mature	0	51	26	1	2	49	11	1	1
Number immature	0	0	0	0	2	1	0	0	0
Mean total length (mm)	–	583[a]	682[a]	736	441	529[a]	631[a]	690	546
Standard deviation	–	52	49	–	150	29	34	–	–
Mean weight (kg)	–	2.74[a]	4.58[a]	7.00	1.60	2.05[a]	3.45[a]	5.20	1.42
Standard deviation	–	0.95	1.02	–	1.54	0.36	0.54	–	–
Visceral fat index	–	1.3	0.8	1.0	2.0	1.1	0.7	2.0	1.0
Standard deviation	–	0.8	0.6	–	1.4	0.9	0.6	–	–
Gonadal somatic index	–	20.5	23.1[a]	26.1	30.6	22.6	35.7[a]	25.6	na
Standard deviation	–	4.8	6.5	–	7.9	7.6	15.7	–	–
Number		47	24	1	2	45	8	1	0

[a] Significant difference within age group between strains (t-test, P < 0.05).

Table 26.–Catch rates (fish per 100 angler hours) of three strains of brown trout stocked into Lake Charlevoix by year class and age during 1993–96. Catch rates were standardized to a stocking rate of 50,000 fish of each strain.

	Year stocked				
Age	1991	1992	1993	1994	1995
			Seeforellen		
2	–	2.163	–	0.110	0.555
3	0.462	0.569	–	0.036	–
4	0.088	0.109	–	–	
5	–	0.039	–	–	–
			Wild Rose		
2	–	2.230	1.766	0.268	0.140
3	–	0.763	0.525	0.195	–
4	–	0.092	0.039		
			Plymouth Rock		
2	–	–	0.225	–	–
3	0.200	–	0.177	–	–
4	0.017	–	0.078	–	–

Table 27.–Estimated catch of brown trout by strain and year for Lake Charlevoix. Assumes stocking rate of 50,000 fish per strain and fishing effort of 80,000 angler hours per year.

	Year			
Strain	1993	1994	1995	1996
Seeforellen	2,100	115	175	504
Wild Rose	1,784	610	708	299
Plymouth Rock	160	14	142	62
Total	4,044	739	1,025	865

Table 28.–Estimated catch at age and return of three strains of brown trout stocked into Lake Charlevoix during 1993–96.

Year stocked	Age	Catch	Percent return
		Seeforellen	
1991	3	648	1.3
	4	28	0.1
Total		676	1.4
1992	2	1,451	2.9
	3	87	0.2
	4	50	0.1
	5	16	<0.1
Total		1,604	3.2
1994	2	125	0.3
	3	33	<0.1
Total		158	0.3
1995	2	455	0.9
		Wild Rose	
1992	2	1,784	3.6
	3	226	0.5
	4	91	0.2
Total		2,101	4.2
1993	2	384	0.8
	3	358	0.7
	4	25	<0.1
Total		767	1.5
1994	2	258	0.5
	3	168	0.3
Total		426	0.9
1995	2	106	0.2
		Plymouth Rock	
1991	3	160	0.3
	4	1	<0.1
Total		161	0.3
1993	2	13	<0.1
	3	142	0.3
	4	62	0.1
Total		217	0.4

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