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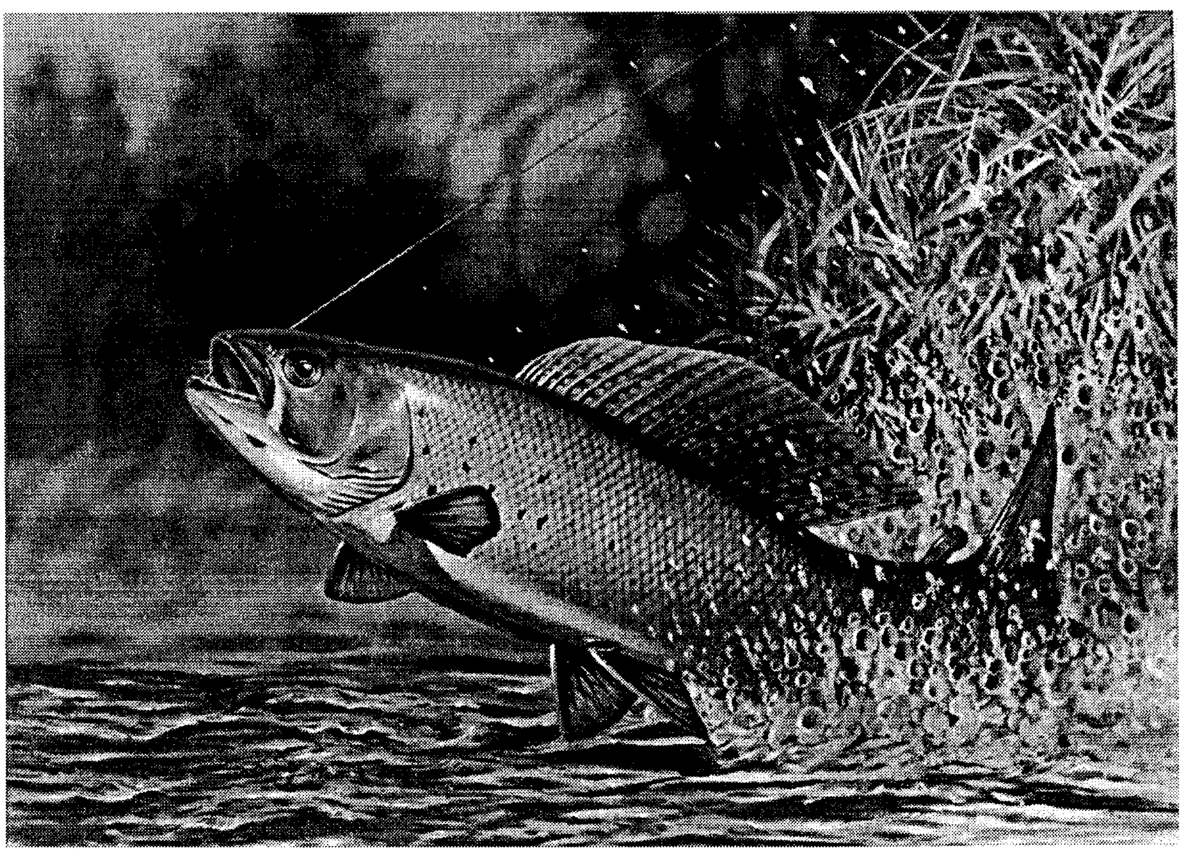

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Evaluation of the Reintroduction of the Arctic Grayling into Michigan Lakes and Streams

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Abstract.—Between 1987 and 1991 the State of Michigan stocked 145,000 yearling Arctic grayling *Thymallus arcticus* into 13 inland lakes and 7 streams in northern Michigan. Arctic grayling were reared in Michigan. Eggs sources were wild Arctic grayling populations in Meadow Lake, Wyoming (1987-1990 stockings) and Providence Creek, a tributary of the Mackenzie River, Northwest Territories, Canada (1988 stocking). Arctic grayling survived well in lakes where other fish species were either absent or sparse. Good survival to age 5 occurred in only one lake which was closed to fishing, patrolled to detect poachers, and held only a few brook trout *Salvelinus fontinalis* competitors. Predation by fish, competition for food, episodes of low pH (in some Upper Peninsula lakes), hooking mortality, illegal harvest, and furunculosis infections present in stocked Arctic grayling were the probable causes of the high mortalities observed in many lakes.

Most Arctic grayling stocked in rivers disappeared within 6 months. It appeared that most Arctic grayling quickly migrated from the stocking site in both small Upper Peninsula streams and larger Lower Peninsula streams. Migration downstream into river reaches and impoundments with high temperatures and large populations of predatory and competitive fish species probably caused large losses of Arctic grayling stocked in the Lower Peninsula rivers. Dams on these rivers block movement back upstream. Additional mortality was attributed to furunculosis infections, and possibly to parasitism by Chestnut lamprey Ichthyomyzon castaneus in the Manistee River.

Arctic grayling generally grew well the first season in lakes where there were few other fish species and where food (such as zooplankton) was abundant. Arctic grayling growth beyond the first year was good in some, but not all, lakes where the density of Arctic grayling and other fish species was low. Most Arctic grayling in rivers accrued little growth before they disappeared.

At least 70% of East Fish Lake and Fuller Pond Arctic grayling were mature at age 3 at total lengths of about 27-29 cm.. Some fast-growing Arctic grayling matured at age 2 in lakes. Ripe age-3 male and female Arctic grayling from Fuller Pond were the same size as age-2 ripe Arctic grayling from East Fish Lake. Mature Arctic grayling did not migrate into the inlet tributaries of either East Fish Lake or Fuller Pond although both tributaries appeared to have good spawning habitat. Arctic grayling did however, (during the April-May spawning period) move into the lake outlet streams where they were caught in fish traps. No reproduction of Arctic grayling was detected in any Michigan lake or river. Many Arctic grayling were caught by anglers from lakes where Arctic grayling survival was good. Most Arctic grayling caught by anglers from rivers were caught at a small size during the first few months after they were stocked. Hooking mortality of 355 Arctic grayling caught from lakes on artificial flies and lures was 1.7%.

European settlers first identified Arctic grayling *Thymallus arcticus* in Michigan during the 1860s (Metcalf 1961). The Michigan grayling evidently occupied all large rivers in Michigan's Lower Peninsula north of a line between the White River on the west and the Rifle River on the east (Vincent 1962). The only river known to be inhabited by Arctic grayling in Michigan's Upper Peninsula was a short reach of the Otter River in Houghton County (East 1930; Juetten 1973).

Michigan grayling were primarily stream dwellers although there are a few records of catches from lakes including the Traverse bays in Lake Michigan and Thunder Bay in Lake Huron (Hallock 1877; Harris 1884; Creaser and Creaser 1935). Arctic grayling were the major game fish species present in these streams where they flourished during the mid-1800s. Although brook trout *Salvelinus fontinalis* were widespread and abundant in streams in Michigan's Upper Peninsula during the middle of the 1800s they were known to live in only a few of the northernmost Lower Peninsula streams such as the Jordan, Boyne, Boardman, and Ocqueoc rivers (Vincent 1962). Historical records indicate that by the 1870s huge numbers of Arctic grayling were being caught from Michigan's Lower Peninsula rivers. At the same time the range of the brook trout was extended both naturally and through the efforts of early fish culturists. In addition, the exotic rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* were introduced into many rivers during the late 1800s.

Concurrently, exploitation of the Michigan's vast stands of virgin white pine and other timber species began. Most northern Michigan rivers were used as conduits to float logs to downstream collection and milling sites during the spring high water period when Arctic grayling spawn. Floating logs required the clearing of centuries of accumulation of large, woody debris from the channels, deepening of shallow riffles, and construction of dams to impound water that could be abruptly released to provide surges of water to propel the logs downstream. Large vegetation on the river banks and in the floodplains that would impede free drift of logs downstream during the log drives was also removed. This activity destabilized stream beds and banks and mobilized massive quantities of soil, much of it glacial outwash sand, which in turn filled pools and plugged the interstices in gravel beds. The changes wrought to channel morphology and stability of stream beds and banks by the log drives persist to this day. Stream channels in this region today are generally believed to be wider and shallower with more sand substrate.

Arctic grayling populations in Michigan's Lower Peninsula rivers declined precipitously beginning in the 1880s and were virtually gone by the turn of the century. The most common hypotheses for the Arctic grayling's demise are logging activity, competition from introduced exotic fish species, and overfishing (Bissell 1890; Mershon 1923; Creaser and Creaser 1935; Hubbs and Lagler 1958; Vincent 1962). Vincent (1962) presented convincing evidence that Arctic grayling declined in many streams before exotic species were either present or established and before watersheds were extensively logged. Thus, early declines were presumably due to overfishing. For example, Vincent (1962) tabulated records of Arctic grayling catches from the Au Sable River from which showed that the first anglers to fish the stream could catch Arctic grayling immediately downstream from the Village of Grayling but within a few years it was necessary to go farther and farther downstream before good catches could be made. He noted a similar decline in fishing success for sections of the Manistee River before logging activity was extensive and before trout were common.

Arctic grayling populations in Alaska and the Northwest Territories of Canada have also exhibited declines in abundance, size, and mean age that were attributed to angler harvest (Wojcik 1955; Falk and Gillman 1974; Grabacki 1981; Armstrong 1982).

In other Michigan rivers various combinations of competition from exotic trout species, logging activity, and heavy fishing pressure occurred concurrently during the late 1800s so that their individual roles in the Arctic grayling's decline and extinction cannot be determined. These factors undoubtedly had additive effects on Arctic grayling mortality and reproductive success in many rivers. Regardless of the specific causes of the Arctic grayling's extinction in individual Michigan rivers it is clear that the Arctic grayling could not adapt to the ecological changes wrought by man. Because Arctic grayling had evolved in extremely stable groundwater-stream environments they were sensitive to perturbation. By 1936 Arctic grayling could no longer be found in the Otter River, the last stream in the state known to contain Arctic grayling (McAllistor and Harington 1969).

The earliest attempts to extend the range of Michigan grayling took place in 1877 when adults were transferred from the Manistee River to one lake and three streams in Calhoun, Jackson, Kalamazoo, and Van Buren counties (Fukano et al. 1964). Additional adult Arctic grayling were transferred to streams outside their known native range in 1880 and 1925. None of the plants were successful. Stocking records kept by the State of Michigan indicate that between 1900 and 1933 over 3,330,000 Montana strain Arctic grayling fry were stocked into Michigan rivers and lakes. Most rivers stocked during this period were within the Arctic grayling's known historical range. Leonard (1940a) reported that Arctic grayling from these plants were rarely caught by anglers and he found no evidence that any of the stocked fish reproduced. Between 1934 and 1941 over 70,000 Arctic grayling, primarily yearlings, were stocked into lakes and streams. Although some survived for a few years, particularly in lakes, they again failed to reproduce. Between 1958 and 1960 a combination of nearly 300,000 fingerlings, eyed eggs, and fry were planted in Lake Manganese and its inlet, French Annie Creek in Keweenaw County. Some Arctic grayling from these plants survived, grew, and moved into adjacent lakes and streams but they again failed to reproduce. The latest effort to reestablish Arctic grayling in Michigan waters began in 1987. The most complete summary of Arctic grayling stocking records I could assemble for the period between 1877 and 1991 is appended to this report (Appendix I).

This report is an evaluation of recent grayling stocking efforts (1987-91) made to determine if grayling would survive, grow, and reproduce in some contemporary Michigan river and lake habitats. I attempted to link grayling survival, growth, and reproductive success to physical, chemical, and biotic habitat characteristics of the stocked lakes and streams. The research was intended to determine what Michigan habitats, if any, might be suitable for grayling so that any future stocking attempts could be made into waters where survival, growth, and reproductive success is more likely to occur. The effects of competition by other fish species were assessed by comparing survival and growth of grayling in single- and multiple-species lakes and rivers. Grayling were stocked in some lakes with inlet and outlet streams where maturity and spawning activity could be closely monitored. Limited observations of Arctic grayling movement out of some lakes and within streams were made to determine potential dispersal from stocking sites. Another objective was to determine if lakes with a history of supporting trout fisheries could support Arctic grayling fisheries, and hence provide new angling opportunities. It was anticipated that some Arctic grayling populations would be established and develop into fisheries managed under restrictive gear and harvest regulations. Thus, hooking mortality of Arctic grayling caught on artificial flies and lures was estimated.

Study Areas

Lakes and streams stocked with Arctic grayling from 1987 through 1990 are listed in Table 1. Criteria used to select study lakes included a history supporting adequate survival and growth of trout, remoteness, and an absence or paucity of other fish species. Deer, Sid, and Penegore lakes in Michigan's Upper Peninsula contained no resident fish species before Arctic grayling were stocked. Dutch Fred Lake contained a dense population of yellow perch *Perca flavescens* but was stocked when extra Arctic grayling became available. This lake was also stocked with brook trout in 1987 prior to the Arctic grayling plant. Two other Upper Peninsula lakes, Ackerman and Kettlehole, were treated with rotenone in the spring of 1987 to eliminate their fish populations before Arctic grayling were stocked. When Kettlehole lake was surveyed after Arctic grayling were stocked a number of fish species were collected which had either survived the rotenone treatment or recolonized the lake by negotiating an ineffective outlet fish barrier.

Methyl-orange alkalinity in surface waters of the Upper Peninsula study lakes ranged from 4.0 ppm in Penegore Lake up to 51.0 ppm in Dutch Fred Lake (Table 1). Alkalinity was measured in most lakes when gill nets were set to catch Arctic grayling.

The seven lakes in Michigan's Lower Peninsula selected for Arctic grayling introductions contained an array of resident fish species. These lakes were chosen to test survival and growth of Arctic grayling in the presence of other species. Horseshoe, Kneff, Reid, and Sand #2 lakes were stocked annually with either rainbow or brook trout yearlings. Horseshoe and Reid lakes were also stocked annually with hybrid sunfish. East Fish Lake and Fuller Pond contained small residual populations of brook trout from a 1982 stocking and their progeny. Intensive gill netting prior to the Arctic grayling introduction removed virtually all residual brook trout which were large enough to prey upon Arctic grayling. Although O'Brien Lake was treated with rotenone before Arctic grayling were stocked, later surveys revealed that some fish had either survived the treatment or recolonized the lake by moving upstream through the lake outlet and entered the lake through an ineffective fish barrier structure.

Methyl-orange alkalinity in surface waters of Lower Peninsula study lakes ranged from 80 ppm in Horseshoe Lake up to 175 ppm in East Fish Lake (Table 1).

Spray, Chapel, and Section 34 creeks are small streams (generally less than 3 m wide) located in Michigan's Upper Peninsula. They were treated with rotenone to remove competing fish species before Arctic grayling were stocked in 1987. Spray Creek flows into Lake Superior. Section 34 and Chapel creeks are tributaries of Chapel Lake. Mulligan Creek is a small tributary (less than 3 m wide at the stocking site) to the Dead River in northern Marquette County. The only fish species known to inhabit this stream section were pearl dace *Semotilus margarita*, northern redbelly dace *Phoxinus eos*, and finescale dace *Phoxinus neogaeus*. The Cedar River in Antrim County is a medium sized river with mean widths generally less than 9 m. The most abundant fish species are brown and brook trout, mottled sculpin *Cottus bairdi*, and slimy sculpin *C. cognatus*. The Au Sable and Manistee rivers where Arctic grayling were stocked are large cold-water rivers with mean widths of approximately 50 and 30 m, respectively, near the stocking sites. The most abundant fish species (based on standing-crop biomass) in the sections Arctic grayling were stocked are brown and brook trout and several sucker species.

East Fish Lake and Fuller Pond were closed to public fishing. All other lakes and rivers where Arctic grayling were stocked were open to fishing although it was illegal for anglers to take or possess Arctic grayling from any waters in Michigan. Fishing tackle was restricted by law to artificial lures and flies on a 22.8 km reach of the Au Sable River between the Mio electrical power line and McKinley in Oscoda County. Arctic grayling were stocked at the upstream end and middle of this section of the Au Sable River. Only artificial flies could be legally fished in a 12.1 km reach of the Manistee River between Yellowtrees Landing and CCC Bridge in Kalkaska County. Although Arctic grayling were not directly stocked into this special regulations section of the Manistee River, migrants from the upstream stocking site were present in this river reach. Fishing tackle was restricted to single-point artificial lures or flies in Sand Lake #2 in Grand Traverse County and Dutch Fred Lake in Schoolcraft County. The remainder of the waters where Arctic grayling were stocked could be fished using any legal tackle including bait.

Methods

Lake sampling methods

Arctic grayling were sampled in all lakes except East Fish and Fuller by 38.0-m long by 1.8-m deep monofilament gill nets. Each experimental gill net was subdivided into five panels, each 7.6 m long. Stretched-mesh measure of the panel netting increased in increments of 1.27 cm from 3.81 cm up to 8.89 cm. A minimum of two experimental gill nets were set perpendicular to the shoreline for 24 hours each time a lake was surveyed. The relative abundance of Arctic grayling in lakes other than East Fish and Fuller was evaluated primarily by comparing catch per 24-h experimental gill-net set. Gill-net sampling was conducted between late September and early November.

Samples of dead Arctic grayling from both O'Brien and Dutch Fred lakes were examined after the lakes were chemically treated with rotenone in late fall 1989. Additional information on Arctic grayling in lakes open to fishing was compiled from voluntary angler reports, popular print media reports, and arrest records for illegal possession of Arctic grayling.

Total length of each Arctic grayling collected in nets was measured to the nearest millimeter and each fish was weighed to the nearest gram. Net-caught Arctic grayling were cut open to determine their sex by examining their gonads. Data on length and weight was also recorded for Arctic grayling collected from East Fish Lake and Fuller by non-lethal techniques. I attempted to determine the sex and state of maturity of Arctic grayling collected from these lakes during the spring by applying gentle pressure to the abdomen in an effort to expel gametes. I also classified Arctic grayling collected from these two lakes as males or females based on secondary sexual characteristics but could not be absolutely certain I was correct unless sex products were evident.

Analysis of variance was used to compare sizes of male and female Arctic grayling within individual lake samples. I used Tukey's honestly significant difference test to make multiple comparisons between mean Arctic grayling sizes in different lakes. Tukey's test was also used to compare the size of Arctic grayling from East Fish Lake that had never been Floy® tagged versus those tagged for either 6 or 18 months. A chi-square analysis was used to test for deviation of the male to female sex ratio in Arctic grayling samples from 1:1. Both the ANOVA and chi-square analyses were done using procedures in the SPSS/PC+ software package (Norusis 1988). Statistical test results were judged to be significant for alpha levels less than or equal to 0.05.

Spawning observations

I made daily visual surveys of the small tributary streams entering East Fish Lake and Fuller Pond during the spawning period each spring (approximately from the second week of April through the month of May) between 1988 and 1991. I began observations in the spring as soon as a Arctic grayling was caught in a lake outlet trap and continued observations for about 2 weeks after Arctic grayling quit moving into the outlets. Observations were concentrated near midday with periodic morning and evening observations added. During these surveys I moved slowly along the banks of the tributaries, visually identified fish species, and noted their approximate size.

Population estimation procedures

Population estimates of East Fish Lake and Fuller Pond Arctic grayling were determined by the simple Petersen single census mark-and-recapture method (Ricker 1975). East Fish Lake and Fuller Pond Arctic grayling samples were collected using boat-deployed DC-electrofishing gear, ice and open-water angling, and gill nets at the end of the study. Arctic grayling caught in inclined-screen traps the outlets of East Fish Lake and Fuller Pond were also measured and marked. During each marking period Arctic grayling were given either different fin clips, or injected with Floy® T-bar anchor tags. East Fish Lake and Fuller Pond Arctic grayling populations were estimated 7 and 5 times, respectively, between 1987 and 1991.

The Kneff Lake Arctic grayling population was estimated once in 1987 by the following procedure. During September 1987, 124 adipose-fin-clipped yearling Arctic grayling, which had been held in "show ponds" since April in a hatchery located in the City of Grayling, were stocked into Kneff Lake. Arctic grayling stocked in Kneff Lake during spring 1987 were not fin clipped. I assumed that by November these marked Arctic grayling were randomly mixed with the Arctic grayling stocked in April and that mortality for marked and unmarked Arctic grayling was similar. I used gill nets to collect a sample of Arctic grayling on November 2, 1992. The proportion of adipose-fin-clipped Arctic grayling in this sample was used to compute a Petersen mark-and-recapture estimate of the fall 1987 Kneff Lake Arctic grayling population. The number of adipose-fin-clipped Arctic grayling was subtracted from the estimate before I computed survival between April and September.

Floy tagging procedure

Arctic grayling were marked with serially numbered dark green Floy® T-bar anchor tags (FD-68B) after they were caught in inclined screen traps and by angling during spring 1990 and 1991. Arctic grayling were anaesthetized with tricaine methanesulfonate (MS-222) before the tag was inserted near the anterior base of the dorsal fin. In spring 1990, the tip of the bottom caudal fin lobe of Floy-tagged Arctic grayling was clipped so that tag loss could be determined during the June 1990 recapture run. In 1991, the anal fins of both previously and newly Floy®-tagged Arctic grayling were clipped deeply enough to allow detection at any later sampling date.

River sampling methods

A boat-mounted, pulsed DC Smith-Root Type VI-A electrofisher with two fixed electrodes was used to collect fish from the Au Sable River. The unit was set on 60 pulses per second and operated at approximately 670 volts. Pulse width was adjusted to give an output amperage of 5.75. This same unit was used to sample waters of the Manistee River that were too deep to wade. The entire section of the Au Sable River between the Mio Dam and McKinley was electrofished during November 1987 and June 1988. During August 1989 the river reach sampled extended from the Mio Dam to Alcona Park downstream from McKinley. Wadeable portions of the Manistee River and all sections of the Cedar River surveyed were sampled with continuous non-pulsed 230-volt DC electrofishing gear carried in a 2-m long by 0.7-m wide wooden boat. Wading fisheries workers used two or three capture electrodes to stun fish prior to capture. A minimum of 1.6 km of the Manistee River was surveyed each year. In 1987 these surveys were made at eight stations between Deward and Sharon Bridge. During the other years four river sections were surveyed between Deward and the bridge at State Highway 72 (M-72). A total of approximately 2000 m of the Cedar River was surveyed during 1987 (2 sections) and 1988 (6 sections).

An Advanced Backpack (AbP-3) fish shocker was used to collect fish from rivers located in Michigan's Upper Peninsula. The location and size of stations sampled by electrofishing gear varied between years. In general Upper Peninsula streams were sampled at accessible sites upstream, downstream, and at stocking locations. The length of sampling stations generally ranged from 50 to 400 m. Spray, Section 34, and Chapel Creeks, were not surveyed after 1987-88 since these surveys indicated that no Arctic grayling had survived or remained in these streams. Small-mesh gill nets were used to sample fish in six beaver ponds on Mulligan Creek during 1987. Four of these ponds were located immediately downstream from the stocking site and the other two were approximately 19 and 22 kilometers further downstream. All Arctic grayling collected during river surveys were measured to the nearest millimeter and weighed to the nearest gram.

Arctic grayling survival and movement from stocking sites in rivers was also assessed by tabulating voluntary reports of Arctic grayling catches to district fisheries personnel, myself, popular print media, and reports of arrests for illegal possession of Arctic grayling. A group of volunteer anglers kept fishing logs of their catch and effort on the Manistee River in a continuous series of seven river reaches between Mancelona Road in Otsego County, and Sharon in Kalkaska County, beginning with the 1988 fishing season. These anglers logged approximately 1,000 hours of fishing effort each year from 1988-1991. These Manistee River volunteer anglers measured all fish captured, rounded down to the nearest inch, and recorded observations of attached chestnut lamprey and scars from lamprey attacks.

During July 1988, a visual survey of approximately 20 km of the Manistee River was made at night using underwater lights mounted beneath a boat that was drifted freely with the current. During this survey I attempted to identify the species of fish observed and estimated the approximate size of fish identified as Arctic grayling. I also looked for attached chestnut lamprey.

Hooking mortality procedure

The percentage of Arctic grayling that died following capture from East Fish Lake and Fuller Pond by either artificial lures or flies was determined annually from 1988-91. Arctic grayling were hooked, played until they could be easily netted, unhooked using fingers (or longnose pliers when necessary), and immediately transferred to a 19-L water bucket in the boat, then shifted within 5 minutes to 1.8-m deep by 1.0-m diameter cylindrical floating fine-mesh-nylon holding nets in the lakes. If a hook was deeply imbedded in the throat or gill arches the monofilament line was clipped as close to the hook eye as reasonably possible and left imbedded in the fish. Holding nets placed in East Fish Lake and Fuller Pond were checked for Arctic grayling mortalities 24 hours after capture and again after 48 hours during 1988. After 1988, I held Arctic grayling only 24 hours as surface water temperatures were warmer when most Arctic grayling were caught and the lakes were thermally stratified.

Percentages of Arctic grayling dying during the holding period were determined each year. Binomial 95% confidence limits for mortality estimates were determined from tables in Mainland et al. (1956). Notes on bleeding severity and detailed information on anatomical hooking site were kept by some anglers. I examined all Arctic grayling that died during the holding periods and one other Arctic grayling that was found moribund after release from the holding crate to determine where hook points had penetrated. Mortality estimates were calculated from combined fly-and-lure-caught Arctic grayling to increase sample size and to produce estimates relevant to Arctic grayling fisheries in lakes where only artificial flies or lures are legally permitted. Surface water temperatures were measured during the time when Arctic grayling were hooked and held in live crates. Least squares linear regression analysis was used to examine possible relationships between temperature, fish size, and mortality. Multiple regression analysis was used to determine if both temperature and fish size were related to hooking mortality. Regression analyses were done using procedures in the SPSS/PC+ software package (Norusis 1988). Although the study was not designed to measure delayed mortality, since Arctic grayling were first Floy® tagged beginning in 1990 I was able to identify Arctic grayling which were caught multiple times by anglers, and could identify previously caught Arctic grayling when they were captured in either the lake outlet traps or gill nets at the end of the study.

Results

Survival in lakes

In general, first-season Arctic grayling survival was highest in lakes where few or no other fish species were present. Arctic grayling stocked into lakes during 1987 survived well over the first season in 7 of 10 lakes surveyed (Figure 1, Table 2). Survival between April 1987 and January 1988 (based on mark-and-recapture population estimates) was 52% in East Fish Lake (Figure 1a), and 46% in Fuller Pond (Figure 1b). Only a few brook trout that escaped intensive gill netting were present in either lake during 1987. Survival rates for Arctic grayling during the first season in these lakes were similar to rates observed for brook trout studied in these same lakes during a previous study (Alexander et al. 1991, Figure 1). Arctic grayling survival for the first 5 months after stocking was lower in Kneff Lake (39%) where rainbow trout were also stocked. Survival through the first six months after stocking, indexed as catch per 24-h experimental gill-net set (CPE), was highest in Sid, Ackerman, and Deer lakes where no other fish species were captured or observed (Table 2). Low Arctic grayling survival was associated with the presence of large piscivores such as largemouth bass *Micropterus salmoides* and brown trout. Intermediate levels of survival were typically found in lakes where non-grayling fish species were either non-piscivorous or too small to ingest Arctic grayling.

Poor first-season Arctic grayling survival where other fish species were absent, was documented only in Penegore Lake during 1987, where low levels of dissolved oxygen, alkalinity, and pH were recorded. When the lake was netted during fall 1987 there was no oxygen in waters deeper than 4.5 m and surface water pH was 4.5. Penegore Lake also had the lowest (recorded) alkalinity (4.0 ppm) of any lake planted with Arctic grayling (Table 1). Alkalinity levels less than 10.0 ppm in Deer and Sid lakes were associated with poor first-season survival of Arctic grayling stocked during spring 1988, and poor second-year survival of Arctic grayling that were abundant during the previous fall (1987).

Some Arctic grayling mortality following stocking was caused by furunculosis infections. Some Arctic grayling died from this disease in the hatchery before they were stocked in both 1987 and 1988. However, mortality attributed to this disease was observed at planting sites only in 1988. Approximately 10% of Arctic grayling stocked into O'Brien Lake in 1988 were either dead or lethargic. Thus, the relatively low Arctic grayling survival in this lake was associated with both the presence of disease and competing fish species.

Good Arctic grayling survival in lakes over the second season after stocking was not consistently associated with the absence of other fish species (Figure 1, Table 2). Although second-season Arctic grayling survival was good in East Fish and Ackerman Lakes, which contained few fish other than Arctic grayling, survival was poor in six other lakes surveyed with nets, half of which had few or no competing fish species. Low numbers of Arctic grayling were recovered from Dutch Fred and O'Brien lakes when they were treated with rotenone to remove competing fish species. Alkalinity levels were low in both Deer and Sid Lakes, where second-year survival was low.

Arctic grayling survival through the second season appeared to be inversely related to angling effort in some lakes. In East Fish Lake, which was closed to fishing, 64% of Arctic grayling survived between age 2 and 3 (Figure 1). By contrast, survival through two seasons as measured by the CPE index, was very low in all lakes open to fishing except Ackerman Lake (Table 2). Fishing pressure was low in Ackerman Lake. Although Arctic grayling could not be legally harvested from any waters, voluntary reports of Arctic grayling catches to myself, district fisheries personnel, and arrests for illegal possession of Arctic grayling indicated that Arctic grayling were frequently caught from some lakes where other species could be legally harvested. The generalization that Arctic grayling in waters closed to angling survived well through their second season did not apply to Fuller Pond.

Here, only 10% of age 2 fish survived to age 3.

Significant numbers Arctic grayling survived beyond the third season after stocking only in the two research lakes that were closed to fishing, and where competition from other fish species was low. In East Fish Lake 39% of Arctic grayling survived from age 3 to age 4, and 55% survived from age 4 to age 5 (Figure 1). Fuller Pond Arctic grayling survival was 69% between age 3 and age 4, and 45% from age 4 to age 5.

Differential survival between sexes

Assuming that the sex ratio at the time Arctic grayling were stocked was 1:1 is correct, no evidence of significant differences in survival of male and female Arctic grayling were found during this study. There were 1.09 females for every male among 289 Arctic grayling sampled from East Fish Lake during spring 1989. This ratio had increased to 1.5:1 by October 1991. However, a chi- square test of deviation from a 1:1 ratio for this final sample was statistically insignificant $P = 0.07$. The ratio of females to males in other lakes likewise did not deviate significantly from a 1:1 ratio whenever sample sizes were large enough to allow meaningful comparisons.

Arctic grayling survival in Upper Peninsula streams

Arctic grayling stocked into small Upper Peninsula streams in 1987, 1988, and 1991 either did not survive, or moved away from near stocking sites. Competition with other fish species was not linked to the disappearance of Arctic grayling from these streams during the first season after stocking. No Arctic grayling, and few fish of any species were either captured or observed during summer or fall surveys conducted both up and downstream from stocking sites during 1987. In summer 1988 surveys, native brook trout were caught at a rate of 1 per hour of electrofishing in Section 34 creek, and 40 per hour in Spray Creek. Thus, some trout survived the rotenone treatment applied before Arctic grayling were stocked in 1987. Approximately 95% of the trout caught during the 1988 surveys were young-of-the-year and hence were not likely to compete strongly with the yearling Arctic grayling stocked into these streams in 1987 and 1988. Moreover, the density of trout was low.

Surveys and angler reports suggested that some Arctic grayling emigrated from Upper Peninsula rivers where they were stocked. Movement of one Arctic grayling to the Dead River, downstream from the mouth of Mulligan Creek was documented by an angler who caught a Arctic grayling from the 1987 plant during 1988. Age-0 Arctic grayling stocked into Mulligan Creek during fall 1991 could not be located by electrofishing gear near the planting site 2 weeks after they were stocked. However, an angler reported catching one small Arctic grayling from Mulligan Creek during July 1992.

Arctic grayling survival in Lower Peninsula streams

Most Arctic grayling stocked in Michigan's Lower Peninsula streams disappeared within 6 months. Most angler catches from the Au Sable, Manistee, and Cedar rivers were made during the first 2 months after fish were stocked. Only one Arctic grayling was captured during a November 1987 electrofishing survey of the Au Sable River between the Mio Dam and McKinley (Table 3). No Arctic grayling were captured during a summer 1987 electrofishing survey of the Cedar River and only one Arctic grayling from the 1988 plant was captured during the summer 1988 survey (Table 4). No Arctic grayling were captured during annual summer electrofishing surveys of the Manistee River from 1987-91, or from the Au Sable River during 1988-89.

Both competition and predation were suspected as causes of some Arctic grayling mortality in Lower Peninsula rivers. Suckers (Catostomidae) were the most common fishes collected from the Au Sable River during electrofishing surveys made each year from

1987-89 (Table 3). Suckers were also relatively abundant in some sections of the Manistee River but they were not counted during electrofishing surveys. Brown trout were relatively abundant in all three rivers and anglers frequently reported finding Arctic grayling in the stomachs of large brown trout harvested from the Au Sable and Manistee rivers. Arctic grayling were frequently eaten by walleye *Stizostedion vitreum* in the Au Sable River. One angler reported that 15 of 17 walleye weighing over 2.3 kg, which he caught by the end of May 1987, had Arctic grayling in their stomachs. Some of these large walleye stomachs contained as many as three Arctic grayling.

Some, perhaps most, Arctic grayling emigrated from stocking sites in Lower Peninsula rivers. All extensive movements documented were in a downstream direction. Most Arctic grayling reported caught from the Manistee River were taken downstream from stocking sites. One Arctic grayling was caught from the North Branch of the Big Manistee River, a tributary which enters the mainstem river approximately 30 kilometers downstream from the stocking site. Another Arctic grayling was caught downstream from Tippy Dam in Manistee County during 1988. If this report was authentic the Arctic grayling moved at least 200 km downstream from the stocking site. Angler reports suggested that some Arctic grayling were concentrated in the vicinity of the mouths of coldwater tributaries to the Au Sable River as the 1987 season progressed. One survivor of the 1987 plant in the Au Sable River was caught the next year many kilometers downstream from the Alcona dam. Some Arctic grayling stocked in the Cedar River in 1987 were caught that year in the downstream impoundment named Bellaire Pond. Another was caught during 1989 in the downstream Intermediate River. The paucity of angler or survey catches of Arctic grayling after mid-summer suggests that downstream movement may have increased as waters warmed.

Arctic grayling died in the hatchery due to furunculosis infections and presumably this also affected survival in the rivers after planting in both 1987 and 1988. Deaths attributed to this disease at the stocking sites were recorded only in 1988. The relative number of Arctic grayling deaths attributed to this disease in the Wolf Lake Hatchery prior to the time they were stocked also indicates that the Providence Creek strain stocked in 1988 was more severely affected than the Meadow Lake strain stocked in 1987. The relative number of voluntary angler reports of Arctic grayling catches in all 3 rivers further supports the hypothesis that many Arctic grayling died from furunculosis shortly after they were stocked in 1988. For example, the number Arctic grayling reported caught from the upper Manistee River was 286 in 1987, but only 20 during 1988. Moreover, the lengths of 11 of the 20 Arctic grayling reported caught during 1988 indicated that they were probably stocked in 1987.

Some Arctic grayling stocked into the Manistee River probably were killed by chestnut lamprey. During 1987, 13.5% of the 289 Arctic grayling reported caught by volunteer anglers had either attached lamprey (34 Arctic grayling) or lamprey scars (5 Arctic grayling). Several moribund Arctic grayling with attached chestnut lamprey were reported to me by anglers during 1987. Two of five Arctic grayling caught by volunteer anglers who looked for evidence of lamprey attacks in 1988 had been attacked by chestnut lamprey. Conversely, none of the 16 Arctic grayling I observed with underwater lights during late July 1988 had attached lamprey, although they could have had unobserved wounds. The one Arctic grayling caught by a volunteer angler during the 1989 season showed no evidence of lamprey attack.

Hooking mortality per capture event

Mortality of Arctic grayling caught from experimental lakes on artificial flies and lures was quite low throughout the study. The percent mortality for the total sample of 355 Arctic grayling hooked from 1988-91 was 1.7% (Table 5). The percent mortality of Arctic grayling caught by angling with artificial flies and lures ranged from zero to 11.1% in the 1988-91 samples.

Hooking mortality was related to hook penetration of critical anatomical regions which tended to bleed heavily. The one Arctic grayling that died due to hooking during May 1988 was hooked in the gill arches. Two of three Arctic grayling that died during the 1989 hooking trials had been hooked in either the throat or gill arches. One of the three mortalities had been foul hooked (hooked outside the mouth) in the isthmus and bled heavily. A similar association between hook penetration of these critical anatomical areas and subsequent death was also observed for both Arctic grayling that died during the 1990 hooking trials. All Arctic grayling known to have died due to hooking during the 1988-91 experimental fishing were caught by artificial flies. Relatively few Arctic grayling were caught on lures because they were less efficient at capturing Arctic grayling than flies.

Hooking mortality of Arctic grayling was not significantly related to either the size of Arctic grayling caught, or lake surface water temperatures during the holding period. Damage to the critical throat or gill arch regions by hook points caused most Arctic grayling to die either immediately, or within a few hours, regardless of water temperature. Both small and large Arctic grayling were about equally likely to deeply engulf the artificial flies that caused all the hooking mortality observed.

Delayed mortality of Arctic grayling due to angling was not quantified, but many Arctic grayling survived for a year or more after being caught one or more times. Many Arctic grayling removed from East Fish Lake at the end of the study had fin clips or Floy tags that were applied after they were caught by angling.

Arctic grayling growth in inland lakes

Arctic grayling grew the largest during the first year they were stocked in Deer and Sid lakes where no competing species were present and where no fish had been stocked for a decade or more (Table 6). Mean incremental length increases (growth increments) in both Deer and Sid lakes were over 10.5 cm between April and October 1987. First-season growth increments in these lakes were significantly larger than those in any other lakes evaluated (Figure 2). In East Fish Lake, which also contained a few brook trout, the first-season growth increment was significantly higher than in all other lakes except Deer And Sid (Figure 2). The slowest growth first season growth occurred in Reid and Kettlehole lakes where other fish species were relatively abundant. However, the biomass of fish species other than Arctic grayling collected from lakes was not obviously related to first-season Arctic grayling growth in all the lakes evaluated. For example, growth in Kneff and O'Brien lakes, where other fish species were relatively abundant, was similar to growth in Ackerman Lake where few other fish species were captured.

Differences in the amount of food available to Arctic grayling caused by factors other competition from other fish species probably caused some of the first-season growth differences observed. Ackerman Lake was treated with rotenone before Arctic grayling were stocked and hence both zooplankton and invertebrate foods were probably relatively less abundant than in some lakes with competitors that had not been treated. Food may also have been less abundant in Penegore Lake where low levels of dissolved oxygen and pH were observed. The apparent first-season growth of the one Arctic grayling captured from this lake was 5.0 cm. Zooplankton were the most abundant food item (by volume) in samples of the stomachs of Arctic grayling from Deer and Sid lakes, where Arctic grayling grew fastest. The faster growth of Arctic grayling in East Fish Lake versus Fuller Pond may have been related to relative zooplankton abundance since both lakes had similar numbers of brook trout competitors. Zooplankton are abundant in East Fish Lake and sparse in Fuller Pond (G. R. Alexander, Michigan Department of Natural Resources, personal communication).

Second-season Arctic grayling growth increments did not appear related to the presence of other fish species in the lakes surveyed. There were no significant differences in second-season growth increments between lakes with or without other fish species (Figure 2, Table 2). However, growth was significantly faster in East Fish Lake than in Fuller Pond although both lakes held similar numbers of brook trout. These age-2 Arctic grayling from East Fish Lake were also significantly heavier than those in Fuller Pond (Figure 3).

By the third season after stocking, growth was significantly higher in the lake where densities of Arctic grayling and other fish were very low. The Fuller Pond third-season Arctic grayling growth increment was significantly higher than those observed for East Fish Lake and Ackerman Lake Arctic grayling (Figure 2). Only East Fish and Ackerman lakes held substantial numbers of Arctic grayling three seasons after they were stocked. Moreover, in East Fish Lake the density and biomass of naturally reproduced brook trout increased steadily during the study.

After the third season meaningful comparisons of Arctic grayling growth between lakes could not be made due to the small sample sizes of Arctic grayling collected from lakes other than East Fish Lake. The mean terminal size achieved by Arctic grayling in East Fish Lake during October 1991 at age 5 was 39.5 cm and 539 g (Figure 3). The longest Arctic grayling measured during this study was a 42.9 cm, 672 g male from East Fish Lake that was captured on October 16, 1991. The heaviest Arctic grayling was a 41.7 cm, 792 g female captured in the same net.

Growth differences between sexes

If the assumption that both sexes were of a similar length when they were stocked was correct, males grew longer in most lakes, although differences were frequently not statistically significant. Age-1 Arctic grayling males were significantly longer than females from Ackerman (0.7 cm difference) and Deer lakes (1.5 cm difference). Age-3 male Arctic grayling were significantly longer than females in East Fish Lake (1.5 cm difference) and Fuller Pond (0.6 cm difference). Arctic grayling males from East Fish Lake remained significantly longer through age 5 when the study ended. However, the relative difference in the lengths of males and females remained about the same after age 3. Female Arctic grayling were significantly longer than males only in Kneff Lake at age 1 (2 cm).

Floy tag loss, and tagging effects on growth

Floy® tags did not adversely affect growth of Arctic grayling tagged for 6 to 18 months. I found no significant differences between the mean lengths or weights of Arctic grayling which had never been Floy® tagged (or had undetected lost tags), versus those Arctic grayling tagged for 18 months, or those tagged for only 6 months, when the final fall 1991 sample of 89 Arctic grayling from East Fish Lake was measured.

Tag loss between May and October 1991 was 6.3% as 4 of 63 Arctic grayling recovered with anal fin clips in October 1991 were no longer Floy® tagged. Seventeen of the 63 Arctic grayling had been first tagged during spring 1990. I could not determine (from fin clips) if the four Arctic grayling with missing tags were first tagged during 1990 or 1991.

Arctic grayling growth in streams

First-season Arctic grayling growth in streams could not be accurately determined since so few were captured during surveys and most anglers reported approximate fish lengths. Lengths of Arctic grayling reported caught from the Au Sable, Manistee, and Cedar rivers during the same year they were stocked were rarely more than 3 cm longer than the mean length of Arctic grayling stocked. Most of these Arctic grayling were caught within the first 2 months after stocking. The one Arctic grayling captured from the Au Sable River during the November 1987 electrofishing survey was 6.8 cm longer than the mean length of Arctic grayling stocked. The sole Arctic grayling captured during a July 1988 survey of the Cedar River was 1 cm larger than Arctic grayling stocked that spring.

Growth of Arctic grayling that lived more than one year after being stocked in rivers likewise could not be accurately estimated. Angler estimates for lengths of Arctic grayling caught in Lower Peninsula rivers, which I judged to be age 2, averaged approximately 28 cm long. The largest Arctic grayling caught from these rivers (based on angler reports that I believed were credible) ranged from 33 to 36 cm and were probably 4 years old.

Age at maturity, size at maturity, and spawning movements

Some Arctic grayling in lakes matured at age 2. Sex products could be readily expressed from nearly 14% of age-2 Arctic grayling captured by angling from East Fish Lake during the month of May 1988. Ripe males in this sample averaged 28.7 cm and ripe females averaged 27.1 cm. Only 1 ripe male was found among age-2 Fuller Pond Arctic grayling caught in the outlet trap. Most Arctic grayling in both East Fish Lake and Fuller Pond were probably mature by age 3. Although the actual percentage of mature fish could not be determined, an estimated 70% of the Arctic grayling in East Fish Lake, and 100% of Arctic grayling in Fuller Pond attempted to emigrate into the outlets during the spring 1989 spawning period when they were 3 years old. These fish appeared to be mature. Fuller Pond ripe age-3 males and females were 28.7 and 27.2 cm, respectively. These lengths were almost identical to those of ripe age-2 males and females sampled from East Fish Lake.

In East Fish Lake and Fuller Pond virtually all the Arctic grayling that attempted emigration via the lake outlets did so during the months of April or May. Monthly records of numbers of Arctic grayling caught in fish traps when they attempted to emigrate from either East Fish Lake or Fuller Pond by moving into the outlet streams from 1987-91 are presented in Table 7. Most movement into the outlet fish traps occurred between the last week in April through the middle of May each year from 1989-91. A majority of this movement was concentrated in a 7-day period near the end of April each year from 1989-91.

Arctic grayling were never observed in the inlet streams tributary to East Fish Lake or Fuller Pond during the 1988-91 spawning periods. Water temperatures measured with maximum/ minimum thermometers in the inlet tributaries varied from approximately 3 to 10 °C each year that I searched for Arctic grayling during the spawning period.

Although spawners were never observed in the inlet tributaries, some Arctic grayling apparently did attempt to spawn either in the lakes or elsewhere. Spent Arctic grayling were observed in the outlet fish traps each year from 1989-91. Arctic grayling eggs were sometimes evident on the screens of the outlet traps and occasionally their ventral fins were newly eroded and bloody, possibly from spawning attempts in the traps or elsewhere.

If spawning did occur in the lakes or inlet tributaries, the attempts apparently did not produce young Arctic grayling. All Arctic grayling captured or observed, to date, in East Fish Lake and Fuller Pond have been from the 1987 stocking. Because so few Arctic grayling stocked in streams survived or remained in residence I never observed or heard of any evidence of spawning activity in rivers. I heard no reports of small Arctic grayling caught by anglers that could be progeny of the Arctic grayling stocked in Michigan rivers.

Discussion

Survival in lakes

The good survival of Arctic grayling stocked as yearlings in most Michigan lakes where there were few or no coexisting species is consistent with the survival observed following plants in Michigan lakes in the past, and plants of yearlings or fry into lakes without competing fish species in other states (Micklus 1961; Curtis 1977; Shapovalov et al. 1981; Skaugstad 1988). First-season survival of Arctic grayling was also good in some Michigan lakes that contained limited numbers of salmonids, particularly when few of these salmonids were large enough to prey upon

Arctic grayling. Arctic grayling populations in Lobdell Lake California, established from a 1970 plant, have persisted to this day, coexisting with other salmonid species (E. Gerstung, California Department of Fish and Game, personal communication). Curtis (1977), however, reported that although Arctic grayling historically coexisted with cutthroat, they did not usually fare well when coexisting with brook, brown, or rainbow trout.

The presence of populations of large predatory fishes, particularly largemouth bass, in Michigan lakes where Arctic grayling were stocked appeared to reduce their survival more than competition for food. For example, the extremely emaciated Arctic grayling from Kettlehole Lake exhibited good survival in the presence of many small individuals of other fish species for the first 6 months after stocking. Alternatively, their feeding may have been hindered by impaired vision caused by intense infections of *Ornithodiplostomum* sp. in their optic lobes and the surrounding area of the brain (Muzzall 1990). Arctic grayling from other Michigan lakes were not emaciated whether survival was either good or poor. This again suggests that predation had larger effects on survival than food competition. Kruse (1959) described Arctic grayling population in Grebe Lake in Yellowstone National Park that coexisted with a population of rainbow x cutthroat trout hybrids although both species ate similar amounts of similar invertebrate food items. However, Leonard (1940a) examined food habits of Arctic grayling and bluegills stocked in Ford Lake Michigan and concluded that direct competition for food resulted in a reduction in Arctic grayling populations.

Water quality effects on survival in lakes

It is possible that episodes of low pH killed Arctic grayling in some Upper Peninsula lakes. In lakes contained no fish species other than Arctic grayling, near-total Arctic grayling mortality occurred only in the 3 lakes (Deer, Sid, and Penegore) where alkalinities less than 10 ppm were measured. Surface water pH levels as low as 4.5 have been recorded in all 3 lakes. More than 10 years before this study, alkalinities in Deer and Sid lakes ranged from 1 to 9 ppm, and pH ranged from 4.5 to 5.9, over several years of observation (Galbraith 1982). Schneider (1983) observed that pH of soft-water lakes may vary considerably from 1 year to the next as well as diurnally and seasonally. Although I could find no definitive references to the pH tolerance range of Arctic grayling, other important water quality parameters such as dissolved oxygen and temperature were believed to be within the Arctic grayling's tolerance range. Feldmeth and Eriksen (1978) estimated that adult Arctic grayling die when oxygen levels fall to 2.2 ppm at 17 to 18°C and 1.6 ppm at 4 to 5°C. I found no evidence that minimum dissolved oxygen tolerance levels were exceeded in any Michigan lakes where Arctic grayling were stocked.

Angling and hooking mortality effects on survival in lakes

I believe that illegal harvest of Arctic grayling and hooking mortality contributed to their decline in lakes open to fishing. Detection of Arctic grayling poaching at remote lakes was unlikely. East Fish Lake, which is closed to fishing and patrolled nearly every day, supported good Arctic grayling survival from stocking through age 5. Survival was also quite good in Ackerman Lake, which is visible from a major highway. Moreover, this lake contained virtually no other fish species so law enforcement officers could safely presume that anglers fishing the lake were targeting Arctic grayling. However, after Arctic grayling in Ackerman Lake grew to a desirable size (for eating) few survivors were found.

Due to their high catchability, many Arctic grayling probably died after being caught from multi-species lakes on baited hooks. A majority of anglers who fish for trout in small Michigan inland lakes typically use small easily swallowed natural baits to attract fish. Past investigations showing hooking mortalities ranging from 35 to 48.5% for fish caught on baited hooks strongly suggest that Arctic grayling caught on bait would also suffer high mortality (Shetter and Allison 1955; Stringer 1967; Hunsaker et al. 1970; Warner and Johnson 1978). Although it was illegal to fish with bait on some lakes where Arctic grayling were stocked, these regulations are sometimes violated.

The hooking mortality (1.7%) of Arctic grayling caught on artificial flies and lures during this study indicates that gear restrictions applied to angling for Arctic grayling in Michigan lakes could minimize unintended graying mortality. Falk and Gillman (1975) reported that the mortality of fly- caught Arctic grayling from Great Slave Lake was only 2.6% after they excluded mortalities attributed to handling or transport conditions. Approximately 13% of 977 Arctic grayling caught on spinners and artificial flies, and tagged from the upper Chena River in Alaska did not survive capture, retention and handling (Grabacki 1981).

Although no significant relationship between water temperature and Arctic grayling hooking mortality was found during this study, observations of Arctic grayling behavior suggests they were more stressed by capture at higher temperatures. Arctic grayling caught at higher water temperatures during this study generally required longer periods of time to regain their equilibrium at the water surface before swimming down into the holding nets. Investigators reporting that hooking mortality tends to be greater at higher water temperatures include Klein (1965), Hunsaker et al. (1970), Dotson (1982), Plumb et al. (1988), and Nuhfer and Alexander (1992). Tack (1972) reported complete survival of 64 Arctic grayling caught by angling with flies or spinners at temperatures ranging from 11 to 13 °C.

Reproduction in lakes

The apparent failure of Arctic grayling to reproduce in East Fish Lake, which contained a large spawner population, and an inlet stream that conformed to literature descriptions of suitable spawning and rearing habitat was unexpected. The apparent lack of movement of mature Arctic grayling to the inlet tributaries was likewise puzzling since a majority of mature Arctic grayling attempted to migrate downstream into the lake outlet during spawning periods. The Arctic grayling in East Fish Lake and Fuller Pond were progeny of a stock that spawns primarily in the 1 to 2-m wide intermittent inlet to Meadow Lake, Wyoming. Arctic grayling, many of them derived from the Meadow Lake, Wyoming stock, have spawned successfully in inlets to lakes in Montana, Washington, Colorado, Utah, Wyoming, and California (Emig 1969; Curtis 1977; Peterman 1972; Rieber 1983). However, many Arctic grayling also spawn in the outlets of lakes and have colonized some western lakes and streams via downstream drift of fry. Curtis (1977) reported successful reproduction of Arctic grayling in numerous Wyoming lakes that had only intermittent inlet tributaries. He observed that spawning was often so successful that lake populations frequently grew too large to support good growth rates. Temperatures in the inlets to both East Fish Lake and Fuller Pond during the periods when Arctic grayling moved only into the outlet traps were well within ranges reported in the literature for spawning Arctic grayling (Kruse 1959; Reed 1964; Emig 1969; Bishop 1971).

Possibly Arctic grayling did not spawn in the inlets of East Fish Lake and Fuller Pond because they had not been imprinted there. Tack (1980) suggested that complex migration patterns become imprinted in juvenile Arctic grayling when they follow adults to spawning and feeding areas. Kruse (1959) observed that spawning Arctic grayling from Grebe Lake in Yellowstone National Park tended to return to the same streams where they were marked the previous year although some straying occurred. Although imprinting of young Arctic grayling to spawning habitats to facilitate returns of adults appears sensible, past experience in Michigan shows that imprinting does not assure successful reproduction. Between 1958 and 1960 Montana-strain Arctic grayling were stocked as fingerlings, eyed eggs, and fry into Manganese Lake and the inlet tributary French Annie Creek in Keweenaw County, Michigan. Although survivors from these plantings, ranging from 19 to 43 cm in length, were later observed or caught in Lake Fanny Hooe, Manganese Creek, Manganese Lake, and French Annie Creek, no Arctic grayling reproduction was ever detected.

Growth in lakes

The average first-season annual total length growth increments attained by Arctic grayling stocked in Michigan lakes were nearly identical to annual growth increments reported for five Wyoming lakes classified as having good growth (Curtis 1977). Arctic grayling stocked in Michigan lakes were substantially larger by age 3 than Arctic grayling in Alaska's Fielding Lake and Tangle lakes (Reed 1964; Baker 1988), but except for Arctic grayling stocked in Ackerman and East Fish lakes few fish survived beyond this age. The finding that male Arctic grayling tend to be longer than females of the same age has been reported for some other Arctic grayling populations (Kruse 1959; Reed 1964; Peterson 1968; Bishop 1971; Peterman 1972).

Size and age at maturity

In East Fish Lake, where Arctic grayling grew well, some age-2 fish matured in 1988 at a mean length of 28.3 cm. Fuller Pond Arctic grayling, which grew more slowly, matured a year later at about the same size. A majority of these Meadow Lake strain Arctic grayling in both East Fish Lake and Fuller Pond were mature at age 3. This link between Arctic grayling growth and age at maturity has also been observed in lakes in the western U. S. where faster-growing Arctic grayling tend to mature at younger ages (Kruse 1959; Curtis 1977). Arctic grayling populations in Alaska and the Northwest Territories, where growth is generally slower, mature between age 3 and age 8, and again maturity appears related to both size and age (Wojcik 1955; Reed 1964; Falk and Gillman 1974, 1980; Falk et al. 1980; Armstrong 1982).

Floy tag loss and effects on growth

The insignificant effect of anchor tags on growth found for Arctic grayling in this study has been previously reported for other fish species (Rawstron 1973; Tranquilli and Childers 1982; Eames and Hino 1983). However, other investigators have reported reduced growth of anchor-tagged fish (Carline and Brynildson 1972; Gunn et al. 1979; Scheirer and Coble 1991). Since Arctic grayling in this study were first tagged at age 4, when growth was slower than at younger ages, tags may have been less likely to effect growth. Bergman et al. 1992 argued that external tags with internal anchors are more likely to have biological effects than implanted tags.

The 6.3% tag loss by Arctic grayling during 6 months residence in East Fish Lake falls toward the lower end of the range of tag losses reported for other fishes. Anchor tag losses ranging from 2 to 100% have been reported, depending upon the fish species and size, habitat, and the length of time fish were tagged (Keller 1971; Carline and Brynildson 1972; Ebener and Copes 1982; Dunning et al. 1987; Franzin and McFarlane 1987; Waldman et al. 1991). Generally tag retention is better for fish species tagged at a larger size. Kratt (1985) reported that some Arctic grayling tagged with Floy FD-68B T-bar internal anchor tags retained them for nearly 10 years. The same tag was used during this study. He tagged most Arctic grayling when they were 3 or 4 years old.

Survival in rivers

Competition and predation by other fish species could be one reason Arctic grayling rapidly disappeared from Lower Peninsula rivers, but can not account for their disappearance from Upper Peninsula rivers. Many authors have cited competition by other fish as the probable cause of declines or extinction of Arctic grayling populations (Curtis 1977; Reed 1964; Vincent 1962; Nelson 1954). Evidence of fish predation on Arctic grayling in the Au Sable and Manistee rivers was documented. The downstream movement of Arctic grayling documented during this study also would have increased their probability of being eaten by predatory fishes dwelling in downstream impoundments and warmer river reaches. Historical accounts of fish species found in Arctic grayling-dominated rivers mention suckers, shiners, whitefish, and pike as cohabitants in Michigan rivers (Hallock 1873; Mather 1874, 1875). The only known exception to this depauperate fish community where Michigan grayling were abundant was the Otter River which historically contained approximately 20 fish species, including brook trout (Taylor 1954).

Higher temperatures in some of today's altered rivers increases the competitive advantage of other fish species. Eriksen (1975) and Feldmeth and Eriksen (1978) hypothesized that Arctic grayling prefer and function best at lower temperatures than brook, brown, and rainbow trout and hence cannot compete successfully with them in warmer streams. They noted that with few exceptions Arctic grayling and cutthroat trout dominate fish communities only in colder headwater streams. Maximum critical temperatures for Arctic grayling are significantly lower than those for brook, rainbow, and brown trout (Eriksen 1975; Feldmeth and Eriksen 1978). LaPerriere and Carlson (1973) reported a median temperature tolerance limit range of 22.5 to 24.5 °C for Arctic grayling longer than 20 cm from Alaska's Chena River, that were acclimatized at 8.0 °C.

Although there is ample evidence that Arctic grayling do not compete well with some other fish species, the historical record does not suggest that competition caused the near instantaneous extinction of Arctic grayling observed in this study. Vincent (1962) observed that in many Michigan and Montana waters, historical populations of Arctic grayling persisted for 15 to 20 years as populations of exotic species such brook and brown trout built up, and then declined over the following 15- to 20-year period. Although the Arctic grayling population in the Bighole River, Montana is presently in a serious state of decline it has coexisted with a brook trout population for many years (Kaya 1990). Thus, competition does not account for the disappearance of Arctic grayling from Upper Peninsula streams, where competitors were absent or sparse, and water temperatures were low.

Downstream movement of Arctic grayling from Michigan river stocking sites was documented, and appears to be the most likely cause of their disappearance from most Michigan rivers. Some movement may have been induced by high water temperatures. Au Sable River angler reports received during 1987 suggested that at least some Arctic grayling sought thermal refuges at the mouths of coldwater tributaries of the Au Sable. Schallock (1966) observed Arctic grayling migrating upstream into colder tributaries of Alaska's Chatanika River during periods of high water temperature (18 °C). This temperature is exceeded during much of the summer in the Au Sable River reach where Arctic grayling were stocked. Maximum temperatures over 22.0 °C were recorded during 1990 in the Au Sable River reach between the Mio Dam and McKinley Bridge. Movement to avoid high temperatures does not readily account for the Arctic grayling's rapid disappearance from either the Cedar River, or the Upper Peninsula rivers stocked, because temperatures in these rivers rarely exceed 18 °C.

The Arctic grayling's preference for large rivers probably accounts for their relatively more rapid disappearance from rivers other than the Au Sable and Manistee. Historically, Arctic grayling were most common in larger mainstem Michigan rivers, and today Arctic grayling in Montana's Big Hole River also are most common in the mainstem river and in tributaries near confluences with the main river (Vincent 1962; Liknes 1981; Kaya 1990). Kaya (1990) speculated that some western streams, where stocked Arctic grayling did not survive or remain resident, were too small and turbulent to provide good habitat.

The tendency for Arctic grayling to migrate appears to be determined, at least in part, by genetics. Arctic grayling stocked into Michigan water during 1987 were obtained from a lake-dwelling, stream-spawning strain of fish from Meadow Lake, Wyoming. New populations established from this stock in Wyoming have been most successful in lakes having inlet or outlet streams (Curtis 1977). Curtis (1977) hypothesized that this genetic strain of Arctic grayling is not adapted to permanent stream existence as adults were seldom found in inlets or outlets of Wyoming lakes except during the spawning season. Montana strain Arctic grayling stocked during April 1940 in the Fuller Creek drainage, a tributary to Hunt Creek in Michigan, moved downstream rapidly (Leonard 1940b). Kaya (1989, 1990) found that there may be a genetic basis for movement in response to current by young Arctic grayling, which would tend to keep Big Hole River Arctic grayling within a stream, while young from populations that spawn in lake inlets and outlets have movement responses that would tend to return them to rearing lakes. Angler reports indicated that Meadow Lake, Wyoming strain Arctic grayling stocked in Michigan rivers frequently moved downstream from stocking sites.

River-strain Arctic grayling also are known to make extensive movements. Arctic grayling stocked into Michigan waters during 1988 were reared from eggs obtained from a strain that spawns in Providence Creek, Northwest Territories. Tagged spawners from this stock were recovered from a 65 km stretch of the Mackenzie River and the mean distance traveled was 45 km (Falk et al. 1982). Tack (1980) summarized data on the highly complex movement patterns of Arctic grayling in Alaska. While some Alaskan Arctic grayling appear to be relatively sedentary, tagging studies have shown that others make extensive seasonal movements. Contemporary Arctic grayling populations in Montana also appear to exhibit similar movements between wintering and spawning areas (Shepard and Oswald 1989; 1990). Vincent (1962) stated that many early observers believed that the Michigan grayling was sedentary but I do not believe that these early observers could have reliably distinguished migrant and resident Arctic grayling without the aid of techniques such as tagging. If migration tendency is genetically determined, then many river strains stocked into Michigan rivers would die after they migrated into inhospitable habitats. Impoundments, mortality caused by hydroelectric turbines, and lack of fish ladders on dammed Michigan rivers would definitely reduce the survival of Arctic grayling that migrate downstream. Dams may have been an important cause of declines and losses of fluvial Arctic grayling populations in Montana streams (Kaya 1990).

I believe that many Arctic grayling stocked during 1988 into rivers died shortly after they were stocked from the effects of furunculosis infections contracted in the hatchery. Although Arctic grayling stocked in both 1987 and 1988 were infected, Arctic grayling deaths attributed to furunculosis were observed at stocking sites only during 1988. Moreover, many Arctic grayling stocked in 1987 were caught early in the trout season before they either died or migrated, whereas very few Arctic grayling stocked in 1988 were reported caught from rivers.

Predation by chestnut lamprey probably caused some Arctic grayling mortality in the Manistee River. Hall (1963) calculated that as many as approximately one-third of trout 17.8 cm and longer in the Upper Manistee River may die due to attacks by chestnut lamprey. However, since he made his estimates using confined fish, it is possible that he overestimated mortality. Since Michigan grayling and chestnut lamprey coexisted in the Manistee River historically, when Arctic grayling were abundant, it is evident that Arctic grayling populations can thrive in the presence of chestnut lamprey under some conditions. However, historical population levels of chestnut lamprey are unknown. Logging drives conducted around the time that Michigan grayling became extinct dramatically altered the channel morphology of the Manistee River and may have increased the availability of chestnut ammocoete habitat, thereby enhancing chestnut lamprey populations. The fact that Arctic grayling quickly disappeared from other Michigan rivers where they were stocked strongly suggests that by chestnut lamprey predation was not the primary cause of death.

Angling mortality and illegal harvest of Arctic grayling undoubtedly caused some mortality of Arctic grayling stocked in the Au Sable and Manistee rivers but there is no evidence that Arctic grayling were caught in great enough numbers to account for their rapid disappearance. Vincent (1962) reported that over harvest of Arctic grayling seriously depleted the original Michigan grayling populations in the Manistee and Au Sable rivers since their decline was well advanced before exotic salmonids were common. He implicated overharvest further by noting that Arctic grayling were already sparse in the Au Sable River immediately downstream from the Village of Grayling before this area was extensively logged.

Reproduction in rivers

Because so few Arctic grayling stocked into Michigan rivers either survived or remained there, it was not surprising that no reproduction was ever detected. The present fragmentation of Michigan's larger rivers by dams (without fish ladders), coupled with the Arctic grayling's documented tendency to make long seasonal migrations, suggests that they will not reproduce in most contemporary Michigan rivers. Arctic grayling stocked into Michigan and Montana streams in the past have also failed to produce self-sustaining populations although in some cases they survived and grew well for a few years after they were stocked (Leonard 1940a; Tyron 1947; Kaya 1990).

Management Implications

This study showed that Arctic grayling populations can be established in some Michigan lakes. Survival seems to be best when the lakes contain few or no competitors, and methyl orange alkalinities are higher than 10 ppm. The lakes should not have outlets or most Arctic grayling would probably emigrate at maturity. Arctic grayling seem to grow relatively fast in lakes where zooplankton or other small food items are available.

Good survival and high long-term catch rates will require that fishing gear be restricted to artificial lures and flies. Compliance with these regulations is essential. Ideally the fishing season should be closed during the summer to reduce temperature related hooking mortality. Ice fishing for Arctic grayling should also be discouraged, since they offer little sport at this time of year, and if bait is fished, hooking mortality will be high.

Some additional study of the factors needed for successful natural reproduction of lake-dwelling Arctic grayling would be desirable. Mature Arctic grayling in some Michigan lakes may have emigrated only to lake outlets, rather than to inlets, since outlets provided relatively warmer flowing water during the short period that Arctic grayling spawn. Hence Arctic grayling might reproduce in chains-of-lakes having suitable outlets and a paucity of competitive or predatory fishes.

Arctic grayling are unlikely to either survive well, or reproduce, in contemporary Michigan rivers. Both lake- and river-strain Arctic grayling appear to make long seasonal migrations. They seem to need large, cold, non-fragmented rivers with few competing fish species, particularly salmonids, or predatory-sized non-salmonids. Perhaps future river restoration efforts, such as dam removal, will provide some large-river habitats that will better support grayling survival and reproduction.

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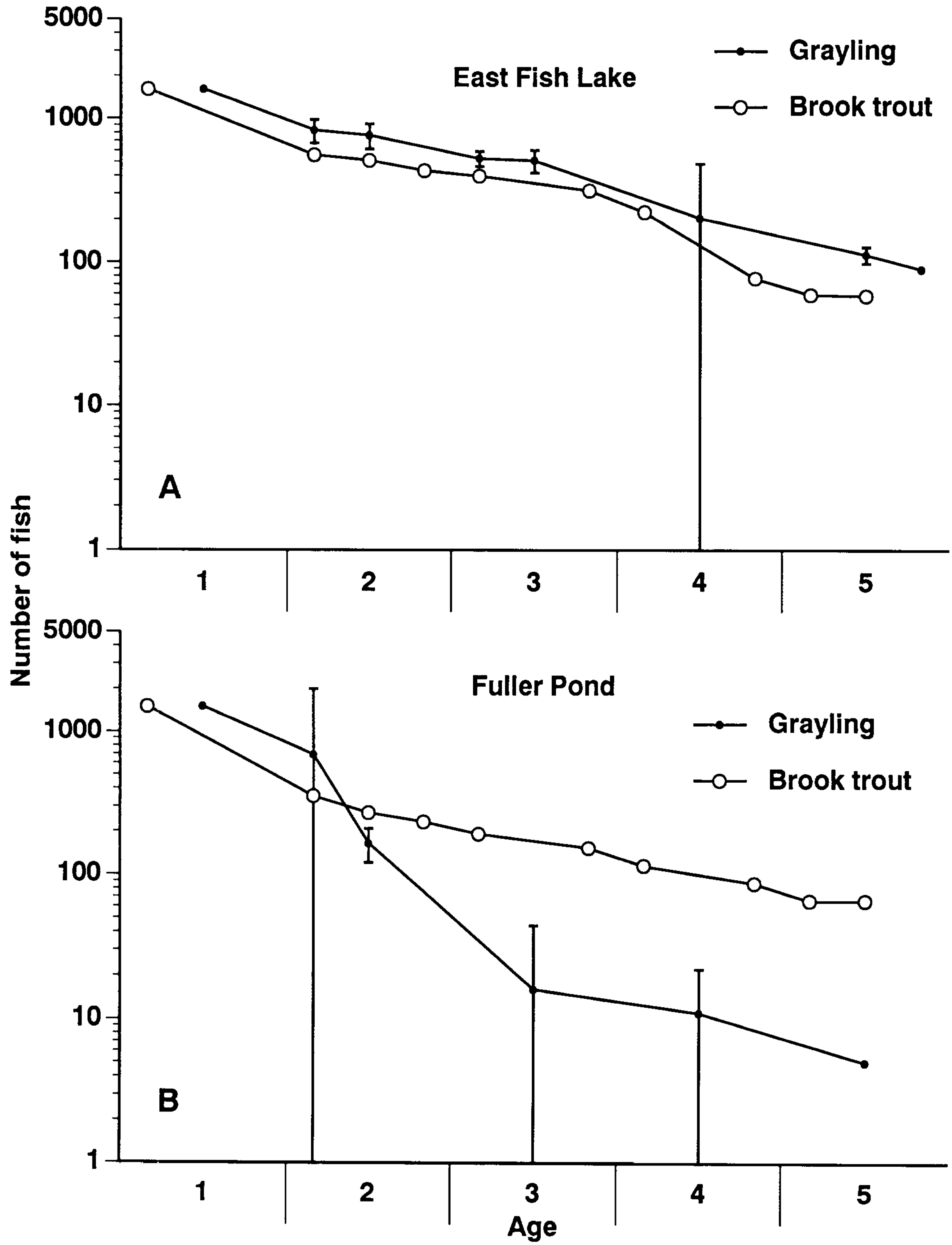

Figure 1.—Comparative survivorship curves for estimated numbers of Arctic grayling (with 95% confidence limits) in East Fish Lake and Fuller Pond between April 1987 and October 1991, versus estimated numbers of Assinica and Temiscamie brook trout between October 1982 and April 1987.

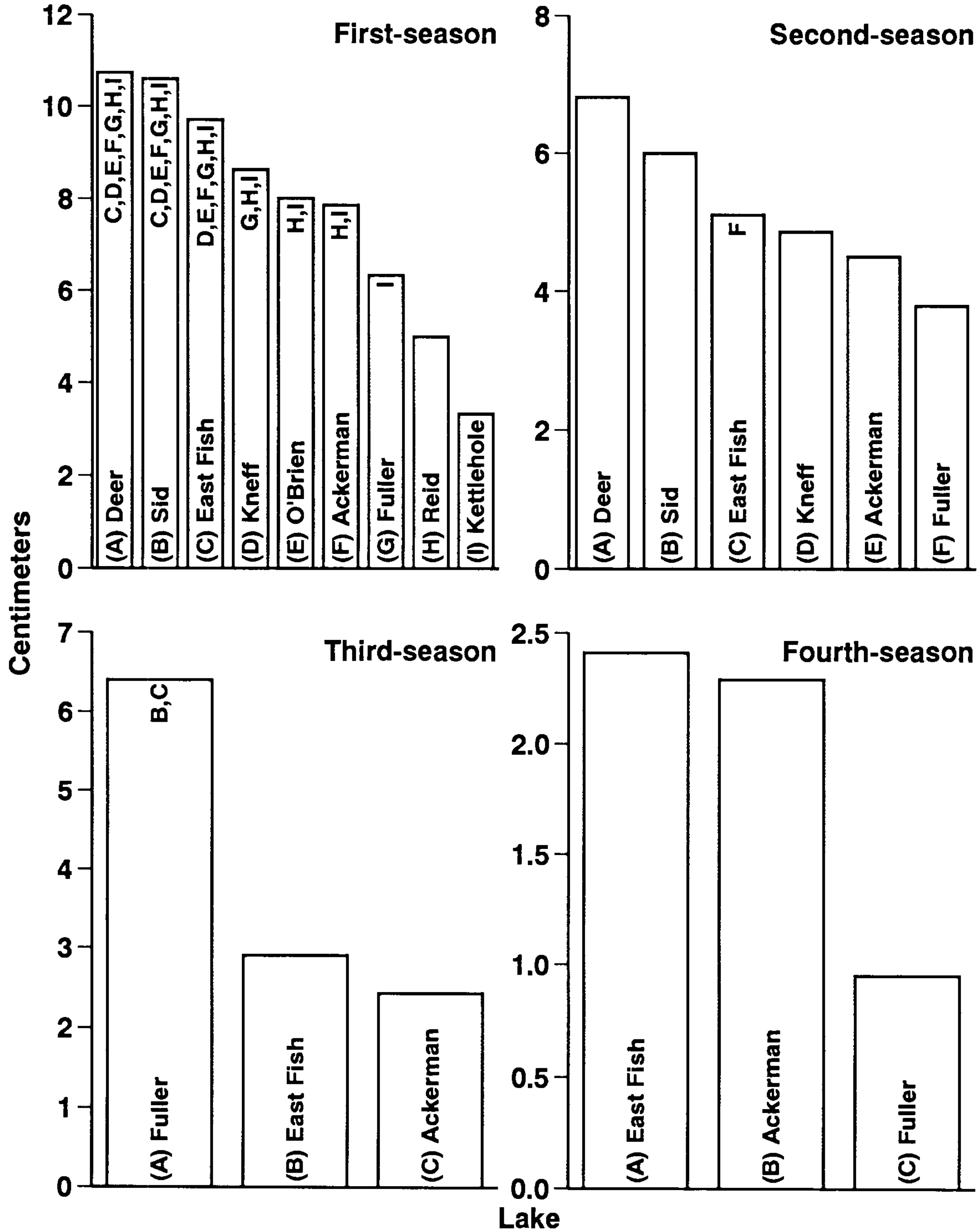

Figure 2.—Comparison of first through fourth season mean growth increments (cm) of Arctic grayling stocked into Michigan lakes. Each lake is identified by a letter. Letters shown at the top of the bars for a lake indicate that the mean growth increment for Arctic grayling in that lake are significantly larger than those in the lakes with the listed letter code.

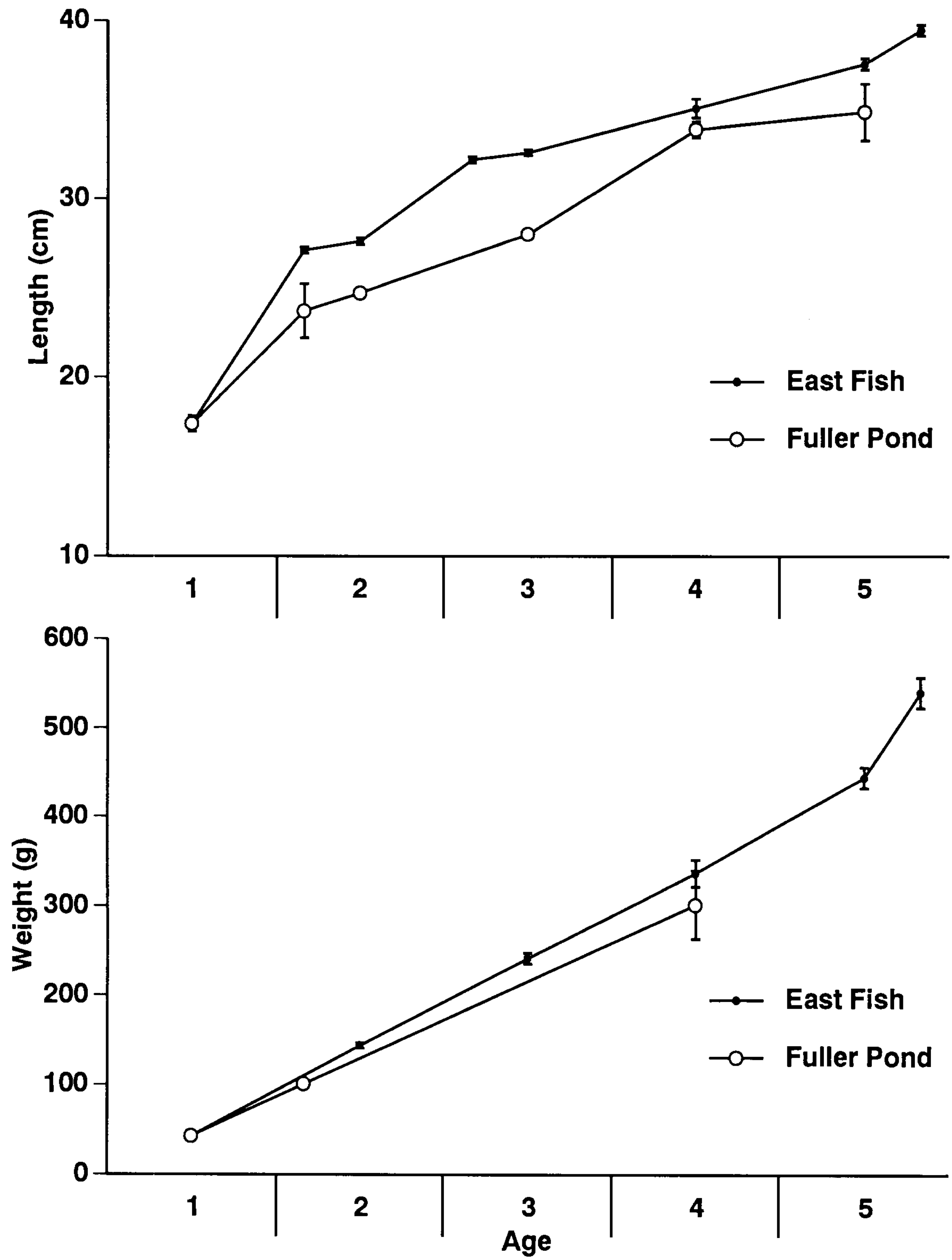

Figure 3.—Comparison of mean total lengths and mean weights of Arctic grayling (with 95% confidence limits) in East Fish Lake and Fuller Pond between April 1987 and October 1991.

Table 1.—Numbers and age of Arctic grayling stocked (1987-1990) by location and year. Lake size is in hectares and methyl-orange alkalinity is in parts per million.

Name	County	Lake size	Alkalinity range	Year	Number	Age
Lake						
Ackerman	Alger	5.7	11.0-16.0	1987	1,375	1
				1988	926	1
				1990	1,400	0
Deer	Luce	4.9	7.5-9.0	1987	1,200	1
				1988	840	1
				1990	900	0
Dutch Fred	Schoolcraft	11.1	51.0	1987	1,000	1
East Fish	Montmorency	6.5	175.0	1987	1,600	1
Fuller Pond	Montmorency	6.1	149.0	1987	1,500	1
Horseshoe	Alcona	6.3	80-85	1987	1,500	1
Kettlehole	Alger	2.8	—	1987	700	1
Kneff	Crawford	5.3	90.0	1987	1,424	1
O'Brien	Alcona	4.2	174.0	1988	1,334	1
Penegore	Houghton	4.0	4.0	1987	1,000	1
Reid	Alcona	5.3	34.2-68.4	1987	1,500	1
Sand #2	Grand Traverse	6.9	117	1987	1,700	1
Sid	Luce	4.0	8.0	1987	1,000	1
				1988	1,000	1
				1990	646	0
Total				1987	15,499	1
				1988	4,100	1
				1990	2,946	0
River						
Au Sable	Oscoda			1987	40,032	1
				1988	13,795	1
Cedar	Antrim			1987	3,000	1
				1988	2,938	1
Chapel Creek	Alger			1987	800	1
Manistee	Crawford & Kalkaska			1987	31,139	1
Mulligan Creek	Marquette			1987	2,000	1
Section 34 Creek	Alger			1987	5,400	1
				1988	4,136	1
Spray Creek	Alger			1987	5,290	1
				1988	4,259	1
Total				1987	87,661	1
				1988	34,762	1

Table 2.—Relative abundance (catch per 24-hour gill-net set) of Arctic grayling and other primary fish species caught during experimental gill-net surveys conducted in 10 northern Michigan lakes from fall 1987-90. Dash (—) indicates no netting was conducted that year.

	Study lakes										
Species	Acker-man	Deer	Horse-hoe	Kettle-hole	Kneff	O'Brien	Pene-gore	Reid	Sand Lake #2	Sid	Year
Arctic grayling	24.5	24.0	0.0	21.5	14.3	—	0.3	3.0	—	28.5	1987
	19.0	1.0	—	—	3.0	9.5	—	—	0.0	2.0	1988
	18.5	—	—	—	—	2.5	—	—	—	—	1989
	8.0	—	—	—	0.3	—	—	—	—	—	1990
Brook trout	0.0	0.0	0.0	0.0	0.0	—	0.0	0.0	—	0.0	1987
	0.0	0.0	—	—	0.0	0.5	—	—	1.0	0.0	1988
	0.0	—	—	—	—	0.5	—	—	—	—	1989
	0.0	—	—	—	0.0	—	—	—	—	—	1990
Brown trout	0.0	0.0	0.0	0.0	0.0	—	0.0	0.5	—	0.0	1987
	0.0	0.0	—	—	0.0	2.0	—	—	0.0	0.0	1988
	0.0	—	—	—	—	2.0	—	—	—	—	1989
	0.0	—	—	—	0.0	—	—	—	—	—	1990
Rainbow trout	0.0	0.0	3.3	0.0	3.3	—	0.0	7.3	—	0.0	1987
	0.0	0.0	—	—	6.5	0.0	—	—	0.0	0.0	1988
	0.0	—	—	—	—	0.0	—	—	—	—	1989
	0.0	—	—	—	7.3	—	—	—	—	—	1990
White sucker	0.0	0.0	0.0	5.0	0.3	—	0.0	0.0	—	0.0	1987
	0.5	0.0	—	—	0.0	3.0	—	—	0.5	0.0	1988
	0.5	—	—	—	—	2.5	—	—	—	—	1989
	0.0	—	—	—	1.3	—	—	—	—	—	1990
Yellow perch	0.0	0.0	0.0	5.5	0.3	—	0.0	0.3	—	0.0	1987
	0.0	0.0	—	—	0.0	0.0	—	—	0.0	0.0	1988
	0.5	—	—	—	—	1.0	—	—	—	—	1989
	1.5	—	—	—	0.0	—	—	—	—	—	1990
Largemouth bass	0.0	0.0	12.3	10.0	0.0	—	0.0	0.0	—	0.0	1987
	0.0	0.0	—	—	0.0	0.5	—	—	2.0	0.0	1988
	0.0	—	—	—	—	1.5	—	—	—	—	1989
	0.0	—	—	—	0.0	—	—	—	—	—	1990
Hybrid sunfish	0.0	0.0	8.3	0.0	0.0	—	0.0	8.3	—	0.0	1987
	0.0	0.0	—	—	0.0	0.0	—	—	2.5	0.0	1988
	0.0	—	—	—	—	0.0	—	—	—	—	1989
	0.0	—	—	—	0.0	—	—	—	—	—	1990

Table 3.—Catch rates and size ranges (cm) for fish collected from the Au Sable River, Michigan using a boat-mounted, pulsed DC electrofishing unit, 1987-89.

Species	Year	Catch per hour	Length	
			Minimum	Maximum
Arctic grayling	1987	0.2	25.2	25.2
	1988	0.0	—	—
	1989	0.0	—	—
Brown trout	1987	38.7	10.9	59.7
	1988	8.4	15.5	65.0
	1989	11.7	16.3	59.2
Rainbow trout	1987	2.9	14.7	50.0
	1988	0.6	23.4	25.7
	1989	0.5	24.9	52.1
Brook trout	1987	0.2	17.0	17.0
	1988	0.2	12.7	12.7
	1989	0.2	21.1	21.1
Northern hogsucker	1987	36.0	7.9	46.5
	1988	30.2	10.4	57.7
	1989	62.4	12.2	46.5
White sucker	1987	16.0	11.9	47.8
	1988	87.1	15.2	50.5
	1989	67.5	14.7	48.8
Silver redhorse	1987	4.0	52.3	70.4
	1988	70.9	43.2	67.8
	1989	31.0	45.2	79.5
Hornyhead chub	1987	0.2	19.3	19.3
	1988	0.2	12.2	12.2
Creek chub	1987	1.0	11.7	21.1
Common shiner	1987	0.4	16.5	18.0
	1988	0.2	17.5	17.5
	1989	0.2	16.0	16.0
Longnose dace	1987	2.9	5.8	10.9
	1989	0.2	7.0	7.0
Logperch	1987	0.2	10.9	10.9
	1989	0.2	10.0	10.0

Table 3.—Continued:

Species	Year	Catch per hour	Length Minimum	Length Maximum
Blackside darter	1987	0.4	5.3	7.9
	1989	0.2	6.0	6.0
Rock bass	1987	0.2	15.8	15.8
	1989	2.7	11.7	24.1
Northern pike	1987	0.4	61.0	61.2
	1989	0.2	46.7	46.7
Round whitefish	1987	2.9	16.8	43.9
	1988	0.4	35.3	37.8
	1989	1.7	29.2	41.1
Walleye	1987	9.2	14.5	38.1
	1988	3.2	19.6	69.9
	1989	11.6	24.6	76.7
Smallmouth bass	1988	0.4	34.3	69.9
	1989	1.6	16.3	36.8
Stonecat	1988	0.4	19.8	20.8
Yellow perch	1989	0.3	17.8	21.6

Table 4.—Number of fish collected per hour of electrofishing in 1987-88 from the Cedar River, Michigan.

Species	Year 1987	Year 1988
Arctic grayling	0.0	0.2
Brown trout	147.0	127.7
Brook trout	6.0	33.2
Mottled and slimy sculpin	5.0	46.8
White sucker	0.0	2.7
Brook stickleback	0.0	3.8
Central mudminnow	0.0	2.5

Table 5.—Percent mortality and binomial 95% confidence limits for Arctic grayling caught by angling with artificial flies and lures, 1988-91.

Date	Number caught	Percent mortality	Mean length (cm)	Mean weight (g)	Temperature range (°C)
May 1988	216	0.5 (0.01-2.6)	27.7	144	12.2-15.6
May-Jun 1989	110	2.7 (0.6-7.8)	32.6	241	16.1-19.4
Jun 1990	18	11.1 (1.4-34.7)	35.1	336	18.3-21.1
May-Aug 1991	11	0.0 (0.0-28.5)	34.9	334	15.0-25.5
Total	355	1.7 (0.6-3.6)	29.8	190	12.2-25.5

Table 6.—Mean length (cm) and weight (g) in parentheses, of Arctic grayling stocked and collected from Michigan lakes from 1987-90.

Lake stocked	Year	Stocked size	Size of Arctic grayling sampled, Fall 1987	1988	1989	1990
Ackerman	1987	13.2	21.5	25.8	32.0	34.3
		—	(83)	(134)	(261)	(315)
	1988	14.2	—	20.8	25.1	25.7
		(21)	—	(66)	(121)	(126)
Deer	1987	18.3	29.0	35.8	—	—
		(43)	(228)	(521)	—	—
	1988	14.6	—	27.7	—	—
		(26)	—	(207)	—	—
East Fish	1987	17.4	27.1	32.2	35.1	37.6
		(43)	(141)	(332)	(336)	(443)
Fuller	1987	17.4	23.7	27.5	33.9	34.9
		(43)	(97)	(152)	(301)	(330)
Kettlehole	1987	18.3	21.6	—	—	—
		(43)	(56)	—	—	—
Kneff	1987	18.3	26.3	31.2	—	36.8
		(43)	(139)	(223)	—	(377)
O'Brien	1988	21.2	—	29.2	35.1	—
		(86)	—	(203)	(364)	—
Penegore	1987	18.3	23.9	—	—	—
		(43)	—	—	—	—
Reid	1987	18.3	23.7	—	—	—
		(43)	(90)	—	—	—
Sid	1987	18.3	28.8	34.8	—	—
		(43)	(227)	(459)	—	—
	1988	14.6	—	27.1	—	—
		(26)	—	(211)	—	—

Table 7.—Number of Arctic grayling captured in inclined screen traps at the outlets of East Fish Lake and Fuller Pond between April 1987 and December 1991.

Lake and year	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fuller Pond													
1987	—	—	—	8	15	0	1	1	4	3	10	10	52
1988	3	1	0	43	0	0	0	0	0	1	0	0	48
1989	0	0	0	37	4	0	0	0	0	0	0	0	41
1990	0	0	0	4	2	0	0	0	0	0	0	0	6
1991	0	0	0	1	0	0	0	0	0	0	0	0	1
East Fish Lake													
1987	—	—	—	2	0	0	0	0	0	0	0	0	2
1988	0	0	0	0	1	1	1	0	0	0	0	0	3
1989	0	0	0	164	192	1	0	0	0	0	0	0	357
1990	0	0	0	14	35	0	0	0	0	0	0	0	49
1991	0	0	0	80	0	0	0	0	0	0	0	0	80

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Richard D. Clark, Jr., Editor
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Appendix 1.—Michigan Arctic grayling plants from 1877 to 1991.

Year and county	Stream or lake	Number stocked	Size or age	Annual total
1877				
Calhoun	Goguac Lake	75	adults	
Jackson	Sandstone Creek	75	"	
Kalamazoo	Spring Brook	75	"	
Van Buren	Dowagiac Creek	75	"	
Total				300
1880				
Cass	Dowagiac Creek	60	adults	
Berrien	Mill Creek	32	"	
Total				92
1900				
Charlevoix	Melrose & Bear Creek	30,000	fry or eyed eggs	
Crawford	Manistee River	21,000	" " " "	
Kalkaska	Big Manistee River	75,000	" " " "	
Osceola	Pine River	15,000	" " " "	
Total				141,000
1901				
Crawford	Manistee River	100,000	fry or eyed eggs	
Emmet	Maple River	25,000	" " " "	
Manistee	Bear Creek	25,000	" " " "	
Osceola	Hersey Creek	50,000	" " " "	
Total				200,000
1902				
Otsego	Manistee River	100,000	fry or eyed eggs	
Total				100,000
1903				
Crawford	Manistee River	100,000	fry or eyed eggs	
Emmet	Maple River	50,000	" " " "	
Osceola	Hersey Creek	50,000	" " " "	
Total				200,000

Appendix 1.—Continued:

Year and county	Stream or lake	Number stocked	Size or age	Annual total
1904				
Alcona	North Branch	20,000	fry or eyed eggs	
Crawford	Manistee River	70,000	" " " "	
Total				90,000
1905				
Alcona	North Branch	15,000	fry or eyed eggs	
Crawford	Manistee	50,000	" " " "	
Iosco	Graham Creek	15,000	" " " "	
Montcalm	Handy Creek	15,000	" " " "	
Total				95,000
1906				
Crawford	Manistee River	70,000	fry or eyed eggs	
Mecosta	(No name)	10,000	" " " "	
Montcalm	Handy Creek	15,000	" " " "	
Total				95,000
1913				
Crawford	N. Br. Au Sable River	50,000	fry	
Total				50,000
1914				
Crawford	N. Br. Au Sable River	25,000	fry	
Houghton	Otter River	25,000	"	
Total				50,000
1917				
Cheboygan	Mud Creek	10,000	fry	
Crawford	N. Br. Au Sable River	35,000	"	
Total				45,000
1925				
Gladwin	Cedar River	100	adults	
Total				100

Appendix 1.—Continued:

Year and county	Stream or lake	Number stocked	Size or age	Annual total
1926				
Charlevoix	Hoffman Lake	50,000	fry	
Crawford	Au Sable River	80,000	"	
"	Manistee River, Dewards Dam Pond	60,000	"	
Marquette	Silver Lead Lake & Chocolay River	50,000	"	
"	Trout Lake	25,000	"	
Montmorency	McCormick Lake Headwaters	56,000	"	
"	McCormick Lake	76,000	"	
Oscoda	Au Sable River	28,000	"	
"	Au Sable River (Mio Pond)	52,000	"	
Otsego	Big Chub Lake	60,000	"	
"	Big Springs	20,000	"	
Roscommon	Higgins Lake	70,000	"	
Total				621,000
1927				
Charlevoix	Hoffman Lake	63,000	fry	
"	Thumb Lake	42,000	"	
Cheboygan	Foamer Creek	63,000	"	
"	Bradley Creek	63,000	"	
Crawford	Manistee River (Deward Dam Pond)	63,000	"	
"	Au Sable River (Wakely Bridge)	63,000	"	
Marquette	Silver Lead Lake	90,000	"	
Montmorency	Bass Lake	59,500	"	
"	McCormick Lake	63,000	"	
Oscoda	Big Creek	63,000	"	
Otsego	Corner Lake	48,000	"	
"	Chub Springs	90,000	"	
Roscommon	Higgins Lake	63,000	"	
Total				833,500
1928				
Crawford	Bartlett Creek	25,000	fry	
"	Tributary to River Lake	25,000	"	
"	Tributary to Au Sable	25,000	"	
"	Tributary to Alex Lake	25,000	"	
"	Au Sable (Wakely Bridge)	100,000	"	
"	Manistee River (Dewards Pond)	30,000	"	
"	Manistee River	15,000	"	
Charlevoix	Thumb Lake	40,000	"	
"	Hoffman Lake	40,000	"	
Cheboygan	Lance (Mud) Lake	40,000	"	
"	Silver Lake	40,000	"	
"	Foamer Creek	20,000	"	

Appendix 1.—Continued:

Year and county	Stream or lake	Number stocked	Size or age	Annual total
1928 (continued):				
Cheboygan	Allens Creek	20,000	fry	
"	Burt Lake	45,000	"	
Montmorency	Clear Lake	40,000	"	
"	McCormick Lake	25,000	"	
"	Thunder Bay River	15,000	"	
Oscoda	Au Sable River (Mio Pond)	45,000	"	
Otsego	Chapmans Creek	30,000	"	
"	Ironstone Springs	10,000	"	
"	Chub Springs	40,000	"	
"	Chub Creek	20,000	"	
"	Chub Lake	20,000	"	
Roscommon	Higgins Lake	40,000	"	
Total				775,000
1933				
Gogebic	Mid. Br. Ontonagon River	36,000	4 months	
Total				36,000
1934				
Crawford	N. Br. Au Sable River	3,200	yearlings	
"	E. Br. Au Sable River	3,200	"	
Gogebic	Mid. Br. Ontonagon River	3,600	"	
Kalkaska	Manistee River	2,500	"	
Lake	Pine River at Peterson Bridge	2,000	"	
Oscoda	Big Creek at Luzerne	1,500	"	
Van Buren	Hatchery Springs (Wolf Lake)	500	"	
Wexford	Pine River	3,000	6 months	
"	Pine River	5,000	yearlings	
Total				24,500
1936				
Antrim	Finch River	1,100	yearlings	
Cheboygan	Pigeon River	4,000	"	
Otsego	Au Sable River	1,000	"	
"	Manistee River	1,000	"	
"	Pigeon River	5,000	"	
"	Black River	4,600	"	
"	Sturgeon River	400	"	
"	Ford Lake	5,000	5 months	
Total				22,100

Appendix 1.—Continued:

Year and county	Stream or lake	Number stocked	Size or age	Annual total
1937				
Cheboygan	Hemlock Lake	1,000	18 months	
Emmet	Maple River	3,000	yearlings	
"	Maple River (above dam)	2,000	"	
Lake	Pine River	10,000	18 months	
Mecosta	Buckhorn Creek	3,000	18 months	
Total				19,000
1940				
Alcona	O'Brien Lake	5,000	9-month fingerlings	
Montmorency	Fuller Pond	1,000	" " "	
"	Fuller Creek	4,000	" " "	
Total				10,000
1941				
Montmorency	Fuller Pond	300	22-month adults	
"	Sutton's Pond	200	" " "	
Total				500
1958				
Keweenaw	Lake Manganese	912	fingerlings	
Total				912
1959				
Keweenaw	Lake Manganese	100,000	eyed eggs & fry	
Total				100,000
1960				
Keweenaw	French Annie Creek	100,000	eyed eggs & fry	
Total				100,000
1987				
Alcona	Horseshoe Lake	1,500	yearlings	
"	Reid Lake	1,500	" " "	
Alger	Ackerman Lake	1,375	" " "	
"	Chapel Creek	800	" " "	
"	Kettlehole Lake	700	" " "	
"	Section 34 Creek	5,400	" " "	
"	Spray Creek	5,290	" " "	

Appendix 1.—Continued:

Year and county	Stream or lake	Number stocked	Size or age	Annual total
Antrim	Cedar River	3,000	yearlings	
Crawford	Kneff Lake	1,424	" " "	
"	Manistee River	18,000	" " "	
Grand Trv.	Sand Lake #2	1,700	" " "	
Houghton	Penegore Lake	1,000	" " "	
Kalkaska	Manistee River	13,139	" " "	
Luce	Deer Lake	1,200	" " "	
"	Sid Lake	1,000	" " "	
Marquette	Mulligan Creek	2,000	" " "	
Montmorency	East Fish Lake	1,600	" " "	
"	Fuller Pond	1,500	" " "	
Oscoda	Au Sable River	40,032	" " "	
Schoolcraft	Dutch Fred Lake	1,000	" " "	
Total				103,160
1988				
Alger	Ackerman Lake	926	yearlings	
"	Section 34 Creek	4,136	" " "	
"	Spray Creek	4,259	" " "	
Alcona	O'Brien Lake	1,334	" " "	
Antrim	Cedar River	2,938	" " "	
Crawford	Manistee River	9,634	" " "	
Luce	Deer Lake	840	" " "	
"	Sid Lake	1,000	" " "	
Oscoda	Au Sable River	13,795	" " "	
Total				38,862
1990				
Alger	Ackerman Lake	1,400	4-month fingerlings	
Luce	Deer Lake	900	" " " "	
Luce	Sid Lake	646	" " " "	
Total				2,946
1991				
Baraga	West Branch Huron River	25,230	4-month fingerlings	
Luce	Deer Lake	2,400	" " " "	
Luce	Sid Lake	2,200		
Marquette	Mulligan Creek	10,000	" " " "	
Montmorency	East Fish Lake (inlet)	62,160	fry	
Total				101,990