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DEPARTMENT OF NATURAL RESOURCES

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COVER: A steelhead caught below Berrien Springs Dam on the St. Joseph River.

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Abstract--We evaluated post-stocking survival, returns, homing, and contributions of steelhead smolts of two strains stocked in three southern Michigan warmwater rivers. Post-stocking survival was examined by comparing abundance among various stocking groups in the summer Lake Michigan sport catch during 1988-93. Minimum estimates of river returns were obtained by creel census below the first dam (and by counts at one fish ladder) during 1988-94. For Little Manistee steelhead, post-stocking survival varied among years and decreased as stocking sites moved further upriver. About 50% of mortality on downstream-migrating smolts occurred in the final 8-16 km of the journey. Post-stocking survival was very high for Skamania steelhead stocked in the lower St. Joseph River, but much lower for those stocked upriver in Indiana. Minimum returns to Berrien Springs dam on the St. Joseph River averaged 15-16% for both strains but only 2-3% for Skamania fish stocked in Indiana. Homing of Little Manistee steelhead was strong, both to and within the river. On the average, 77% of adult steelhead recovered at a stocking location within the Grand River had been stocked at that site. Fish stocked at the mouth or in downstream tributary streams did not return upstream to the first dam. Stocked Little Manistee steelhead made up 54-77% of the fall-spring adult returns from the 1988-90 smolt cohorts. Stocked Skamania steelhead made up 82% of summer returns and 17% of fall returns. Little Manistee fish stocked in the Huron River (draining to Lake Erie) matured at only 1.8 lake years (as opposed to 2.6 lake years for those stocked in Lake Michigan) and scales showed unusual signs of mid-summer stress. Stocked steelhead smolts can provide consistent returns and sustain valuable sportfisheries in warmwater tributaries of the Great Lakes. The Skamania strain offers high survival to the open-lake fishery and an extension of the river fishery into summer months; however, their use should be limited to coolwater or coldwater rivers, and potential impacts should be assessed prior to introduction.

Since 1970 large fisheries for steelhead (anadromous rainbow trout *Oncorhynchus mykiss*) have been developed by stocking hatchery-reared juveniles in several southern Michigan warmwater rivers. These successful fisheries provide returning adult steelhead to large urban centers in southern Michigan, Ohio, Indiana, and Illinois.

Growth of these fisheries coincided with the initiation of stocking but contributions of stocked steelhead were never fully evaluated. The Michigan Department of Natural Resources (MDNR) stocked yearling and fall-fingerling parr in several of these rivers during 1969-85 (Figure 1), and substantial fisheries developed in subsequent years (Figure 2; Seelbach 1989). Juvenile steelhead are termed "parr" during their stream-resident phase, and "smolts" as they physiologically transform and migrate in preparation for life at sea (or the Great Lakes). This distinction is size-related; smaller yearlings are typically parr and larger yearlings are smolts. Nearly all fish smolt by age 2. Most stocked parr remain in the river an additional year and can suffer high mortalities. Conversely, smolts imprint to the stocked river and migrate quickly to the lake, minimizing riverine mortalities (Seelbach 1987). Seelbach (1989) found that, for 2 warmwater rivers in southern Michigan, returns of marked yearling parr were fairly low (1-7%), and suggested that most parr died during the additional year of river residence. He speculated that fall-fingerling parr may have suffered similar mortality; and suggested that a sizable portion of returning adult runs may have been strays, as stocking by neighboring states had also increased during this period (Hansen et al. 1991; Breidert and Hudson 1990).

In 1986 MDNR began stocking yearling smolts (Figure 1) with expectations of good imprinting, quick emigration, minimal river mortality, and consequent high returns. MDNR stocks the Little Manistee River strain, a first-generation product of wild winter- and spring-run steelhead collected in the Little Manistee River, a tributary of central Lake Michigan. MDNR has also experimented with the Skamania strain, a domesticated summer-run strain that has been selected over many generations in Washington for early spawning (and thus good hatchery growth) and late maturity (and thus large size at return). The Skamania strain has been propagated in Michigan since 1985 and in Indiana since 1978. Fish ladders were built to provide passage past dams on the Grand (1975-81) and St. Joseph (1975-92) rivers with hopes of spreading a large new fishery for steelhead (and other salmonines) upriver to previously unavailablereaches. Ladders on the St. Joseph River now allow migrating salmonines access to Indiana waters. Since 1985, the Indiana Department of Natural Resources (IDNR) has stocked large numbers of Skamania steelhead smolts and parr (Figure 1a) into the upper river with the intent of building an upriver fishery.

The purpose of this study was to evaluate these major new management programs: stocking yearling smolts into warmwater rivers in southern Michigan; developing upriver fisheries through upriver stockings and construction of fish ladders; and stocking Skamania steelhead. We had the following objectives. (1) To evaluate post-stocking survival, growth, maturity, returns, and relative contribution to seasonal fisheries for Little Manistee steelhead smolts stocked at various sites in three large, warmwater rivers; (2) To evaluate homing of adult steelhead stocked at upriver sites in the Grand River; and (3) To evaluate the performance of Skamania steelhead stocked in the St. Joseph River.

Study rivers

The St. Joseph, Grand, and Huron rivers are warmwater rivers in southern Michigan draining watersheds characterized by gently rolling topography that reflects a patchwork of geologic features including lake plains, end moraines, ground moraines, and outwash plains (Albert et al. 1986). Soils are mostly organic loams and clays, with sands dominating the outwash areas. As most soils are fairly impervious, river discharge is largely surface runoff, however groundwater plays a larger role in certain tributaries that drain outwash plains. Discharge is characterized by low-to-moderate drought flow levels, and low-to-moderate flow stability (Velz and Gannon 1960). Summer fish habitat conditions are typified by low water velocities and moderately high water temperatures (Anonymous 1968).

Southern Michigan is an area of low elevations and gentle relief (Albert et al. 1986). Channel gradients in the study rivers average about 0.6 m/km (3 ft/mi) or less, with steeper reaches of 1.0-2.9 m/km (5-15 ft/mi). Runs and shallow pools, with sand and silt substrates, predominate in low-gradient reaches. Riffles and rapids alternate with deep pools in higher-gradient reaches.

Mild climate, loamy soils, and proximity to transportation routes have attracted intensive agricultural, municipal, and industrial development to these river basins. These land uses have degraded river conditions, intensifying discharge extremes (Ball et al. 1973; Hay-Chmielewski et al. 1994) and degrading water quality (Brown 1944). Significant improvements in water quality occurred following passage of clean water legislation in the 1970s, providing the opportunity for fairly recent recreational developments including fish stocking. However local point-source and basin nonpoint-source concerns still exist (Goudy 1986; Anonymous 1988a). Numerous dams were built on many of the higher-gradient reaches. These have impounded riffle--pool habitats, degraded discharge conditions and water quality, and blocked critical migration routes for certain fishes (Hay-Chmielewski et al. 1994).

Resident fish communities include predators such as smallmouth bass *Micropterus dolomieu*, rock bass *Ambloplites rupestris*, walleye *Stizostedion vitreum*, northern pike *Esox lucius*, channel catfish *Ictalurus punctatus*, and flathead catfish *Pylodictis olivaris*; as well as a variety of abundant catostomids and cyprinids. Pre-settlement fish communities also included potamodromous species (migratory between the Great Lakes and tributaries) such as lake sturgeon *Acipenser fulvescens* (Hay-Chmielewski and Whelan 1994), muskellunge *Esox masquinongy* (Seelbach 1988), and lake whitefish *Coregonus clupeaformis* (Duffy 1994), however these populations were eliminated by the destruction and blockage of spawning habitats.

The St. Joseph River begins in Michigan near Hillsdale, winds southwest into Indiana through Elkhart, Mishawaka, and South Bend, flows northwest back into Michigan through Niles, and enters Lake Michigan near St. Joseph (Figure 3a). The river has 490 km of mainstream and drains an area of 1.1 million hectares (Brown 1944). At Berrien Springs, width is 61-92 m and maximum depth is 6.7 m. Discharge at Buchanan averages 104 m^3/s (3,702 ft^3/s) and is moderately stable; mean August discharge is 61 m^3/s (2,179 ft^3/s) and mean April discharge is 176 m^3/s (6,289 ft^3/s). A number of tributaries enter the lower St. Joseph River, many of which are small, coldwater streams that support resident trout populations. The Dowagiac River, the largest coldwater tributary, enters the St. Joseph River just below Niles.

There are three dams on the Michigan portion of the lower river and one on the Dowagiac River. The first dam is located at Berrien Springs, approximately 37 km upstream from the river mouth. Fish passage is available at the Berrien Springs, Buchanan, and Niles dams in Michigan; and at the South Bend and Mishawaka dams in Indiana (Figure 3a). The Twin Branch dam (in Mishawaka, 38 km upriver from Lake Michigan) is the upstream limit to fish migration. Seven more dams exist on the mainstream upstream of Twin Branch dam.

The Grand River begins near Jackson, flows north through Lansing, then west past Grand Rapids, entering Lake Michigan at Grand Haven (Figure 3b). The Grand River has 765 km of mainstream, and drains 8.8 million hectares, and is the second largest drainage basin in Michigan (Brown 1944). At Grand Rapids, the river is 61-92 m wide and maximum depth is about 2.1 m. Discharge just downstream of Grand Rapids averages 94 m^3/s (3,353 ft^3/s) and mean monthly discharges range from 41 m^3/s (1,474 ft^3/s; August) to 328 m^3/s (11,715 ft^3/s; April). Most tributaries to the river are sizeable warmwater streams, however, several are coolwater or coldwater streams, suitable for trout. The mainstream has eight dams, the first (6th St. dam) being located at Grand Rapids, approximately 64 km upstream from the river mouth. The five most-downstream dams have fish ladders in operation (Figure 3b). The Moores Park dam in Lansing, about 240 km upstream from the river mouth, is the upstream limit to fish migration. Several larger tributaries also have dams which limit fish migrations.

The Huron River begins near Commerce, and then scribes an arc around the western Detroit metropolitan area, passing through Ann Arbor, Ypsilanti, and Flat Rock, before emptying into Lake Erie at Pt. Mouillee (Figure 3c). This river has 218 km of mainstream and drains about 1.4 million hectares (Hay-Chmielewski et al. 1994). Discharge at Ypsilanti averages 17 m^3/s (595 ft^3/s) and mean monthly discharges range from 7 m^3/s (258 ft^3/s; August) to 30 m^3/s (1,089 ft^3/s; April). No coldwater tributaries enter the lower river. Nineteen dams have been built on the mainstream and 98 dams exist within the watershed. The upstream limit to fish migration is the Flat Rock dam (Figure 3c).

Methods

Stocking

Yearling steelhead smolts of the Little Manistee River strain were raised at an MDNR hatchery and stocked annually during 1988-90 at 3 locations in the St. Joseph River system, 6 locations in the Grand River system, and 1 location in the Huron River (Table 1, Figure a-c). Smolts were stocked in late April and early May, just prior to their anticipated smolting period of mid-May. One additional group was raised annually in 1989 and 1990, stocked into a net pen at the mouth of the Grand River (in hopes of improved survival and homing), then released in early May. Finally, parr of the Skamania strain were raised each year at an MDNR hatchery, stocked in the fall into Arden Pond on the St. Joseph River, then released as smolts directly into the St. Joseph River in early May.

For the St. Joseph and Grand rivers, each MDNR stocking group (year, location, and strain) was implanted with unique coded-wire tags (Northwest Marine Technology, Inc., Shaw Island, WA) inserted into the snout, and externally marked with an adipose fin clip. For the Huron River, fish were marked with a unique fin clip each year. Data on immediate retention of tags, fin-clip quality, and total length were collected from a random sample of 200 fish from one stocking group in each river each year.

Fall-fingerling parr and yearling smolts of the Skamania strain were raised at an IDNR hatchery and stocked annually at Mishawaka on the St. Joseph River beginning in 1985 (Table 1, Figure 3). Fall-fingerling parr were stocked in November and yearling smolts were stocked in late March to early April. Each stocking group (year, age) was uniquely marked with a fin clip and total length was measured for a random subsample.

Variation in post-stocking survival

We examined variation in post-stocking survival among stocking groups (stocking location, year, and strain) by comparing the adjusted relative abundances of these groups in the summer, open-lake catch. Marked steelhead were recovered from the Lake Michigan sport catch during June-August 1988-93, at Michigan ports from Grand Haven northward. We accessed data on steelhead that were randomly sampled (N=955) as part of MDNR's lakewide creel census (Rakoczy 1990). We partitioned each summer's catch by lake age and fin clip. IDNR stocking groups were identified by unique fin clips (N=203, 21% of total). Possible MDNR fish were identified by an adipose fin clip (N=150, 16% of total). Fish stocked in the St. Joseph and Grand rivers were then identified and apportioned to stocking groups, based on proportions determined from an independent, coded-wire tag database (N=545, 36% of all adipose-clipped fish). Coded-wire tags were collected by MDNR clerks and donated by anglers. We used data from fish collected during June-August 1988-93 at Michigan ports from Grand Haven northward and from all Wisconsin ports. Proportions of each group determined from each year's sample were expanded as components of a standard annual population of 50,000 fish (arbitrarily chosen), and summed as smolt cohorts. The proportion of the total coded-wire tag sample for each cohort, comprised by each stocking group, was then determined and standardized by the number of fish stocked for that group.

Our analysis was based on the assumption that steelhead from all stocking locations on the St. Joseph and Grand rivers were randomly mixed as one population during the summer months in central Lake Michigan. This assumption was supported by the prevalence and variety of fin-clipped steelhead found in this portion of the lake (marked fish from this study made up about 28% of the summer catch). We avoided ports south of Grand Haven, as these might include mature summer-run Skamania returning to the St. Joseph River that were not part of one mixed population. By sampling the mixed population, and assuming that all fish encountered similar conditions once they arrived at Lake Michigan, we were able to compare relative survival during emigration from the river from various stocking locations. Sampling the open-water catch allowed this analysis without the complicating factor of variable homing to riverine collection sites.

We tested hypotheses that variation in relative abundance in the lake population was related to two factors, stocking year and distance upriver to stocking location. Analysis of variance (ANOVA) was used to test one subset of the data: groups of Little Manistee strain, stocked in the Grand River upstream of the mouth (6 stocking locations, 3 years). All statistical analyses were done using SPSS software (Norusis 1993). As variation in recaptures was influenced by sample sizes that were sometimes small, all tests were run using a fairly liberal α=0.10. A simple linear model of the relationship between distance upriver and relative abundance was developed for all years combined.

We graphically compared relative abundance of groups stocked at other locations with our Grand River model. In addition, relative abundance data were scaled from 0-100% to estimate river mortality. We assumed that relative abundance of groups stocked at the mouth of the Grand River represented 0% river mortality, and absence of fish in the open lake samples represented 100% river mortality.

Minimum percent returns to the first dam

We derived a minimum estimate of returns to the Berrien Springs dam on the St. Joseph River during 1988-94, summing total sport catch and ladder counts at the Berrien Springs dam. Total sport harvest and effort were estimated monthly through random creel census covering the area below Berrien Springs dam downstream to the river mouth. Total effort fishing for steelhead was determined by adjusting the overall effort estimates according to the proportion of anglers who stated that they were actively fishing for steelhead or salmonines. Total ladder counts at the Berrien Springs dam were made as fish were manually counted over the final step during 1988-91, and by continuous video-taping through a counting window from fall 1992 through spring 1994 (Dexter and Ledet 1994). We likewise derived a minimum estimate of returns to the Flat Rock dam on the Huron River during 1988-94, based on total sport catch monitored from below the dam downstream 1.6 km (nearly all fishing for steelhead occurs within this area).

On the St. Joseph River, we recorded total length and fin clips from a random sample of up to 200 angler-caught fish per month. We also measured fin clip, length, weight, stream and lake age, sex, and origin (hatchery or wild) from samples of 20 fish per 25-mm group (N=3,534) collected per season (June-September, October-January, February-April). Ages and spawning checks were read from scales and ages denoted as "stream age.lake age". Hatchery or wild origin was determined based on criteria for first-year scale circuli patterns developed by Seelbach and Whelan (1988). We expanded monthly length-frequencies (by fin clip) to monthly run totals, and then converted lengths to lake ages according to proportions derived from the detailed database. Monthly totals (by fin clip) were expanded to account for proportions of each group that were poorly fin-clipped (and thus unrecognizable as adults) or that may have lost their coded-wire tag (14% of adipose-clipped fish returning to the study rivers did not have a tag); summed by season, and returns analyzed by smolt cohort. Totals were not expanded for IDNR Skamania groups, as data on fin-clip quality were not available.

On the Huron River, data on fin clip, length, weight, stream and lake age, sex, and origin were measured from all steelhead observed by census clerks (N=687). Seasonal catch totals were subdivided by fin clip and lake age. Seasonal totals were corrected for fin-clip quality and summarized by smolt cohort.

On the Grand River we did not estimate total catch but census clerks interviewed anglers and gathered data on fin clip, length, weight, stream and lake age, sex, and origin for harvested steelhead (N=855).

For the St. Joseph and Huron rivers, we estimated minimum percent return of each stocking group to the first dam by dividing the minimum total cohort return for each group by the number stocked. Analysis of the open-water catch suggested that survival was similar for the St. Joseph and Grand rivers. We standardized these relative figures with the absolute values from the St. Joseph River by (arbitrarily) assuming an annual catch of 9,000 steelhead at the 6th St dam, and estimated minimum percent returns accordingly.

Again for the Grand River, we examined the relationship between variation in percent returns, and stocking year and upriver distance of stocking locations using ANOVA and linear regression analysis. We also excluded groups stocked downstream of the first dam, as these were not expected to migrate far upstream. This provided an independent examination of the effects of stocking year and stocking locations. Percent returns of remaining groups were graphically examined in relation to the resulting Grand River model.

Effects of smolt size on returns

We tested the effects of smolt size on returns to the first dam by comparing the frequency distribution of scale radii of stocked smolts (one group per river for all years combined) with that of radii to the smolt check measured from scales of adults returning from the same stocking groups. A Chi-square statistic was used to test for differences between smolt-check radii frequencies measured from smolt and adult scales. For graphing, smolt-check radii were converted to smolt total lengths using simple linear regression (N= 150; $P< 0.0001$, $R^2= 0.53$). Return rates group were derived for each 25-mm length group by multiplying the ratios of smolt/adult radius frequencies for each 25-mm group by a constant, so that the weighted mean return rates were similar to those estimated in this study: 0.16 for St. Joseph and Grand river fish, and 0.016 for Huron River fish.

Relative contributions to river runs

Relative contributions of major groups (stocked and wild) to returning steelhead populations were estimated for the study rivers. For each smolt cohort during 1988-90 in the St. Joseph River, we summed the cohort returns of stocking groups by strain and stocking age. Smolt-cohort returns for unmarked steelhead were derived similarly to those for the stocking groups. We estimated the proportion of unmarked fish of wild origin using proportions in the detailed database corrected for classification errors (we used an error rate of 0.05, based on analyses of our known-origin hatchery fish; Seelbach and Whelan 1988). The relative contribution of each major group was calculated as returns of each group divided by the sum of all groups.

Survival to repeat spawn

For each strain, lake age, and river we calculated mean survival to repeat spawn by following specific age and spawning groups through the cohort analyses. Survival was calculated as the abundance of a group in a given year divided by its abundance the previous year.

Additional population parameters

We calculated mean length at lake age (±2 SE) for each river, by spawning year, sex, and strain. Differences among years and strains were compared for female maiden spawners by examining overlap between error bars.

The proportions of fish maturing at various lake ages were determined for each strain and river. For the St. Joseph River, proportions were determined from the cohort analysis described above. For the Grand and Huron rivers, proportions were determined directly from the detailed databases. Mean age at maturity was calculated for each strain and river; weighted by abundance at each lake age.

Sex ratios were calculated as percent males:females for each strain, lake-age, and river; by season and by spawning year. An overall sex ratio was calculated for each strain and river, weighted by the proportions maturing (indicative of abundance) at each lake age.

Homing to stocking locations

On the Grand River we examined homing to stocking locations by determining the proportion that each stocking group comprised of the total coded-wire tag sample at each location. We tested the hypothesis that the distribution of returning fish was not random by comparing the group frequencies observed at each site with frequencies predicted if fish were randomly distributed throughout the river (frequencies observed at the 6th St. dam). Abundance at the Crockery Creek and mouth sites would not be expected to mirror that at the 6th St. dam, thus maximum values for these sites were further adjusted to resemble those at upstream sites. Distributions were tested using a Chi-square test, with expected frequencies based on those at the 6th St. dam in Grand Rapids.

Results

Open-lake distribution and relative survival

Steelhead stocked in the St. Joseph and Grand rivers inhabited much of central Lake Michigan during summer months, as evidenced by their distribution in the summer open-lake fishery (Figure 4). Little Manistee and Skamania strains showed similar distributions. For the 1988-90 smolt cohorts, fish with Indiana fin-clips and Michigan coded-wire tags made up 21% and 7% of this fishery, respectively.

For Grand River stocking groups (excluding mouth locations), relative survival varied about 4-fold (Table 2). Analysis of variance showed that both stocking year and upriver distance of stocking location had significant effects on relative survival ($P=0.07$ for upriver distance and $P=0.04$ for stocking year). A linear model of upstream distance and relative survival for all years had a significant negative slope ($N=16$, $P=0.01$) and explained 37% of the observed variance (Figure 5a).

Returns to the 6th St. dam in Grand Rapids provided a parallel and supportive analysis (Table 2). In this data set returns again varied about 4-fold. Analysis of variance confirmed the effect of upriver distance ($P=0.03$) but not of stocking year ($P=0.13$). The overall linear model had a significant negative slope ($N=15$, $P=0.04$) and explained 28% of the variance (Figure 5b). In both analyses, all groups stocked in 1990 had consistently low survival, as did groups stocked upriver in 1988.

The relative survival of groups stocked at the mouth of the Grand River was about 4 times the mean for the upper river sites (Table 2; Figure 6a). About 50% of the mortality of downstream-migrating smolts appeared to occur in the final 8-16 km of the journey. No difference was seen between net pen and open release groups. Little Manistee fish stocked in the St. Joseph River appeared to fit the Grand River model, with the Paw Paw River stocking location (near the mouth) showing the highest values (Figure 6a). Skamania groups stocked in the St. Joseph River showed the highest relative survivals. Survival of Skamania steelhead stocked at Arden Pond were about 4 times higher than that for Little Manistee fish stocked at nearby highway I-94. Survival of Skamania fish stocked at the upriver Indiana location was 2-3 times lower than for the Arden Pond site. The effect of stocking year was consistent within these groups, and consistent with the trends seen in the Grand River model.

Mortality rate in upriver reaches of the Grand River was consistent from both open water and 6th St. dam models, and modest at about 0.11% per river km. About 1% of smolts were lost every 22.9 river km.

Graphical comparisons of remaining locations with the Grand River model of river returns were supportive of the open-water findings (Table 2; Figure 6b). Returns of Little Manistee steelhead to the Berrien Springs Dam on the St. Joseph River were arbitrarily fit to mesh with the Grand River model (see above). However, returns were fairly similar between the I-94 and Arden Pond sites, consistent with the model. Returns from Skamania stocked upriver in Indiana were again lower (about 4 times) than those stocked from Arden Pond.

Returns to the first upriver dam

Sport harvest on the St. Joseph River below Berrien Springs dam averaged 8,967 steelhead during 1989-94 (Table 3). Ladder counts averaged 7,121 (Table 4) and thus, the steelhead run averaged at least 16,088 fish. Harvest of Little Manistee steelhead peaked in March-April and October-December, while harvest of Skamania steelhead peaked in July-October (Figure 7). Harvest on the Huron River averaged about 484 during the study period (Table 3). Harvest of Little Manistee and stray fish peaked on both the Grand and Huron rivers during March-April and October-December (Figure 7). Catch rates (fish per angler hour fished for steelhead) on the St. Joseph River averaged 0.04 during summer and 0.07 during fall, winter, and spring (Table 3). Catch rates on the Huron River were lower, averaging 0.02.

Minimum returns to Berrien Springs dam averaged about 16% for Little Manistee groups (N=4) stocked at I-94 and Arden Pond, and 15% for Skamania groups (N=3) stocked at Arden Pond (Figure 6b). Returns of Skamania groups were lower than expected, considering their dominance in the open-lake catch. Returns for Skamania smolt groups (N=5) stocked upstream in Indiana averaged about 2.5%, reflecting the same lower proportion relative to Arden Skamania seen in the open-lake (Table 5). Returns for Indiana's fall-stocked parr Skamania groups (N=5) averaged about 1.5%.

Effects of smolt size on returns

In all three rivers frequency distributions of radii to smolt check were significantly shifted towards larger radii in adult samples than in smolt samples (Figure 8; $P<0.0001$), suggesting that larger smolts had higher survival rates. Return rates tripled as smolt length increased above about 200 mm, tripled again for lengths above about 218 mm, and rose another 2-3 times for lengths above 230 mm (Figure 9).

Homing to stocking location

Homing to the stocking river was strong. Only about 1.4% of the fish recovered in each river had been stocked into the other. Groups stocked into tributaries of the Grand River displayed strong within-river homing (Figure 10). On the average 77% of steelhead recovered at a stocking location had been stocked at that site. Interestingly, an additional 11% had been stocked at the next location downstream, indicating a fair number of fish went upstream one tributary too far.

Groups stocked at the river mouth or in tributaries downstream of the first dam did not return upstream as far as the dam. They showed returns to the dam 3-6 times lower than were expected based on their abundance in open-lake samples (Figure 6b). Groups stocked at the Grand River mouth (both net pens and open release) did not return far upstream.

Composition of river runs

Stocked Little Manistee steelhead made up 54-66% of the 1988-90 smolt cohorts returning during fall-spring to the St. Joseph, Grand, and Huron rivers, respectively (Figure 11). Wild fish made up 0-17% and unidentified strays contributed 17-47% during fall-spring in the three respective rivers. Michigan and Indiana Skamania steelhead contributed 23% and 59%, respectively, to St. Joseph River summer runs. Wild fish in the Lake Michigan tributaries were twice as prevalent during fall as during spring.

Survival to repeat spawn

Mean survival to repeat spawn in the St. Joseph was fairly high and similar between strains (accounting for differential age at maturity; Figure 12). Survival averaged about 48% following the younger lake-ages of maturity but dropped to <1-2% for older fish. Survival to repeat spawn was somewhat lower in the Huron River, averaging about 26% for the earlier lake ages.

Repeat spawners made up 28%, 15%, and 22% of returning Little Manistee strain runs in the St. Joseph River, Grand, and Huron rivers, respectively. Repeat spawners comprised an average of 42% of Skamania strain runs in the St. Joseph River. In all rivers combined, nearly all fish (97%) spawned every year once they matured. In all rivers, only 17% of repeat spawners were spawning for their third time, and 1% for their fourth time.

Population characteristics

Steelhead age at maturity varied from 1 to 5 lake years (Figure 13). Little Manistee fish matured after 1-4 years, with a mean lake-age at maturity of 2.44 years in the St. Joseph River, 2.75 years in the Grand River, but only 1.81 years in the Huron River. Skamania fish matured after 2-5 years and had a mean lake-age at maturity of 3.42 years in the St. Joseph River. Wild fish in the St. Joseph River had a mean lake-age at maturity of 2.50. Wild fish in the Grand River had a mean lake-age at maturity of 2.55.

Wild fish had smolted at either stream age 1 or 2. In the St. Joseph River 24% of the wild run had smolted at age 2, while in the Grand River 46% of the wild run had smolted at age 2.

Steelhead grew well in both Lake Michigan and Lake Erie, gaining about 300 mm in total length during the first 2 years (Figure 14). Mean lengths were similar among cohorts and between strains.

The length-weight relationship for steelhead in the St. Joseph River was:

$$\text{Weight[g]} = 0.000427 * \text{Length[mm]}^{2.426425}$$

$(P<0.0001, R^2=0.91)$.

This analysis included both Little Manistee and Skamania steelhead, as their relationships were indistinguishable.

The length-weight relationship for fish in the Huron River was:

$$\text{Weight [g]} = 0.000021 + \text{Length[mm]}^{2.903564}$$

$(P< 0.0001, R^2=0.97)$.

Sex ratios of returning fish varied with lake age and strain (Figure 15). The weighted overall mean was balanced for the Little Manistee strain at 53:47 (males:females), 45:55, and 55:45 for the St. Joseph, Grand, and Huron rivers, respectively. Females were favored in the weighted mean for the Skamania strain in the St. Joseph River (39:61). Ratios did not vary seasonally in any rivers, except that males predominated in fall in the Huron River (64:36; due to abundant lake-age 1 males).

Discussion

Open-lake distribution and relative survival

Tagged steelhead dispersed throughout Lake Michigan, consistent with past findings (Hansen and Stauffer 1971; Schneider 1992). Use of a wide range of lake habitats is feasible for steelhead, as Wenger et al. (1985) documented rates of movement in eastern Lake Erie of up to 28 km per day. The summer concentration of steelhead catches in central Lake Michigan has been documented by Schneider (1992) and Rakoczy (1992), and suggests that this area may be preferred habitat during summer. Data from the summer offshore fishery in Michigan showed a great mix of tagged fish (27% from this study, 10% other fin clips), and we based our analyses of relative survival on the assumption that all of our groups were randomly mixed in the central portion of the lake. Similar mixed offshore catches have been reported for Indiana waters of Lake Michigan (Braun 1989; Allen 1992), Ohio waters of Lake Erie (Kayle and Hillman 1991), and Ontario and New York waters of Lake Ontario (Haynes et al. 1986; Bowlby et al. 1993); although Bowlby et al. (1993) reported some evidence of non-random mixing of stocks in Lake Ontario.

Much higher initial survival of fish stocked at river mouths, compared with those stocked upriver, suggested that predation upon smolts may be significant in downstream reaches of warmwater rivers. Channel catfish, walleye, and smallmouth bass have been shown to prey to some extent on salmonine smolts (Poe et al. 1991). Hansen and Stauffer (1971) documented significantly higher returns from steelhead smolts stocked at Michigan rivermouth sites than from those stocked at upriver sites. Ward and Slaney (1990) found, in British Columbia, that steelhead smolts stocked upriver suffered about 40% additional mortality compared to those stocked at the river mouth.

Holding fish in net-pens did not increase survival. Savitz et al. (1993) likewise reported no effects of pen-holding on returns of chinook salmon *Oncorhynchus tshawytscha* and coho salmon *Oncorhynchus kisutch* in Lake Michigan.

We found evidence that larger smolts had higher survival, both by comparisons of smolt-check radii on scales, and by the extremely high survival of the very large (230 mm) Skamania smolts stocked at Arden Pond on the St. Joseph River. Each of these observations, however, needs qualification. Comparisons of radii were based on the assumption that the edge of a smolt scale collected at the hatchery is equivalent to the smolt check observed on an adult scale, but any growth that occurred between stocking and appearance of the smolt check would have created the shift in radii frequencies that we observed. A close examination of patterns of scale growth following stocking is needed to clarify this point. The high relative abundance of Skamania steelhead in the open-lake catch may have been related to a possibly higher vulnerability of this strain, rather than to size alone.

With these cautions in mind, our findings did suggest size-biased survival similar to that observed in salmonine populations on the Pacific Coast. Poe et al. (1991) showed that fishes preying on juvenile salmonines emigrating from the Columbia River selected smaller-sized smolts. During April, when 150-215 mm smolts were available in the river, predators (mostly northern squawfish *Ptychocheilus oregonensis*) preferred smolts <180 mm. Only the largest squawfish could eat smolts >180 mm in length. Slaney et al. (1993) reported that returns of stocked steelhead were highly correlated with smolt lengths; survival tripled as lengths increased from about 145 to 180 mm. Ward et al. (1989) likewise found that survival of wild steelhead in the Pacific Ocean was positively correlated with smolt size, and that survival increased about 10% with every 10 mm (between 140 and 260 mm).

In contrast, Skamania smolts stocked upriver into Indiana waters of the St. Joseph River appeared to suffer relatively high mortality during downstream emigration. These smolt groups differed from Skamania groups produced in Arden Pond in several ways. (1) They traveled a longer distance downriver, potentially exposing them to a higher degree of predation. Our results for the Grand River, however, suggested that predation on smolts migrating through upriver reaches was not high. (2) They were stocked about 1 month earlier, in late March or early April. Studies at the Buchanan hydroelectric facility showed that these fish did not emigrate until early or mid May (Anonymous 1991), coincident with emigration times in other systems (Seelbach 1987). Many fish may have been lost to predators (including anglers; Seelbach 1987) during this longer time in the river. (3) These fish were about 40 mm shorter in total length. If predation were size-selective, Indiana fish would have been preyed upon at a higher rate than Arden Pond fish. (4) These fish migrated past 3 hydroelectric dams; many undoubtedly went through turbines at these facilities and died. Mortality of steelhead smolts due to turbines typically ranges from 10% to 50% (Anonymous 1987). On the Grand River, only smolts stocked at Lansing migrated downstream past hydroelectric facilities (at Portland and Webber dams). Impacts of these facilities on smolt mortality were not apparent in our data, however, we did observe poor returns of the Lansing group stocked in 1988. During this low-water spring, a high proportion of the river's flow was diverted through the hydroelectric facilities and turbine mortality may have been greater.

Returns to the first upriver dam

Annual returns of steelhead to the St. Joseph River (about 15,000 fish) were consistent and among the highest recorded for a Lake Michigan tributary. River harvests or returns for Lake Michigan streams have ranged from 1,200 - 17,000 fish (Kruger 1985; Fielder 1987; Seelbach 1989; Rakoczy 1990; Brazo 1992). Annual harvests on the Huron River were consistent and much lower (about 500 steelhead), but not unusual for Lake Erie tributaries (1,000-2,000 in Ohio streams; Kayle and Hillman 1991). Catch rates on the St. Joseph River were good (0.07), while those on the Huron River were only fair (0.02), relative to other good Great Lake stream fisheries that typically have catch rates of about 0.02-0.11 fish per hour (Kruger 1985; Fielder 1987; Anonymous 1988b; Seelbach 1989; Rakoczy 1990; Kayle and Hillman 1991; Allen 1992; Seelbach and Miller 1993). Considerable angling effort was expended on both the St. Joseph (about 155,000 hours over 11 months each year) and the Huron (about 20,000 hours over 5 months) rivers. Effort on the Huron River was for relatively few steelhead, indicating the high recreational value of this fishery to the large urban population of southeast Michigan. Similar effort was recorded for Ohio streams (34,000 hours per stream over 5 months; Kayle and Hillman 1991).

Return rates of smolts to the St. Joseph River (15%) supported previous findings that survival and returns of steelhead smolts in Lake Michigan is typically very high (10-20% or better; Anonymous 1988b; Hansen et al. 1991; Brazo 1992; Seelbach 1993). Survival and returns to the Huron River (<1%) are more in line with lower figures reported for Lake Erie (2-3%; Kayle and Hillman 1991; R. Kenyon, Pennsylvania Fish Commission, 1994, personal communication). However, returns to the Huron River were low, even for Lake Erie streams. Steelhead smolts leaving the Huron River presumably travel across the western basin of Lake Erie to the deeper, colder central and eastern basins to live. These smolts are potential prey for walleyes that are extremely abundant in the western basin, although steelhead have not been observed in the diets of walleye in this basin during May (immediately following smolting; D. Johnson, Ohio Division of Wildlife, 1994, personal communication) nor throughout the rest of the summer (Hartman and Margraf 1992).

Annual variation in returns was substantial, affecting returns roughly as much as upriver distance of stocking. This suggests that returns should be expected to fluctuate by as much as 2-4 times from year to year due to environmental factors (for example return rates to the St. Joseph river might naturally vary between 9% and 18%).

That Skamania steelhead from Arden Pond returned to the St. Joseph River creel at the same rate as Little Manistee steelhead, despite an overwhelming dominance in the open-lake catch, indicated that Skamania are more vulnerable to the open-lake fishery. Schneider (1992) also reported returns of Skamania to Wisconsin streams as comparable with that of other strains. No studies of angling vulnerability among strains have been made. Conversely, Skamania may have returned in abundance to the river, yet been less vulnerable to the river fishery. However, they were vulnerable during June through September, and observations at the Berrien Springs ladder showed dramatic declines in abundance from October on (Dexter and Ledet 1994), supporting the patterns seen in harvest.

Tagged steelhead showed the strong abilities of salmonines to home to the river of stocking and to tributaries within that river. Many adults returning from groups stocked into a downstream reach of the mainstem St. Joseph River (I-94 site) returned 25.6 km upstream past that site and were captured at the Berrien Springs dam. Many also migrated past this dam using the fish ladder (Dexter and Ledet 1994). This pattern of migrating past a mainstem stocking site was also seen by Slaney et al. (1993) on a British Columbia river. They found some concentrating of fish at their mainstem stocking sites but also substantial movements upstream. Adults returning from groups stocked at the river mouth returned to the lower river but did not move far upstream. We could not compare the effects of holding groups in net pens on upriver homing, as very few of these (Recaptures<3 per group) were collected at the dams. Imprinting has been shown to involve a series a cues throughout downstream smolt migration (Quinn et al. 1989) and fish stocked at the river mouth apparently do not imprint adequately to upriver cues to encourage them to continue moving upriver.

Composition of river runs

Steelhead stocked as smolts made up 62-87% of returning adult populations in the three study rivers. This is a much greater contribution than that made by past stocking of yearling parr in these rivers (5-26%; Seelbach 1989). Other evaluations of steelhead smolts stocked into warmwater tributaries of the Great Lakes have also demonstrated significant contributions (47-80%; Bowlby et al. 1993; Schneider 1992; R. Kenyon, Pennsylvania Fish Commission, 1994, personal communication). However, in Ohio streams stocked with London strain rainbows (a domestic rainbow strain, not a true migratory steelhead), stocked yearlings only made up 25% of each river's run, indicating high rates of straying (Kayle and Hillman 1991). Proportions of wild steelhead were low (3-11%) but significant in the St. Joseph and Grand rivers. These self-sustaining populations are believed to have developed since hatchery stocking began in 1970. Peck (1994) described the development of a similar naturalized steelhead population in a tributary of Lake Superior. Stray hatchery steelhead appear widespread in the Great Lakes, comprising at least 10-30% of adult runs in this and several other studies (Braun 1989; Allen 1992; Schneider 1992; R. Kenyon, Pennsylvania Fish Commission, 1994, personal communication; Kayle and Hillman 1991; Seelbach and Miller 1993). In contrast, Seelbach and Whelan (1988) found almost no stray hatchery fish in 2 coldwater rivers tributary to central Lake Michigan.

Little Manistee strain steelhead were only slightly more abundant during spring runs than fall runs, even though gametes were collected from the parental stock during spring. It is not clear whether spring collections captured some fall-run stock or whether the offspring of spring-run stock display bimodal migration timing. Seelbach and Miller (1993) found that, in a tributary of Lake Superior, most stocked Little Manistee steelhead returned during spring.

Survival to repeat spawn

Despite apparently heavy fishing pressure in both open-lake and river environments, survival to repeat spawn appears fairly high for steelhead in Lake Michigan (about 40-50%; Seelbach 1993). In lightly exploited areas of the Great Lakes, survival to repeat spawn has been documented to be as high as 75% (Seelbach and Miller 1993). Schneider (1992) reported that only 5% of Skamania steelhead tagged at first spawning in Wisconsin streams returned to spawn again, however, it was not clear whether this indicated mortality or mortality plus tag loss.

Many studies do not report survival to repeat spawn, but rather the percent of adult runs made up of repeat spawners. The proportions found for Little Manistee steelhead in the study rivers (15-28%) were very similar to 27% reported by Seelbach (1993) for the Little Manistee River. These figures are roughly half of the 54% reported by Seelbach and Miller (1993) for a Lake Superior population exposed to minimal exploitation. The percent found on the Grand River was somewhat lower (15%) and may reflect the more difficult journey many of these fish make past several dams. In 1992 fish ladders began operation on five hydroelectric dams on the St. Joseph River and it will be worth watching for a decrease in the abundance of repeat spawners. Repeat spawners made up a much higher proportion (42%) of the Skamania population in the St. Joseph River--this was surprisingly high considering what appeared to be heavy exploitation in both Lake Michigan and the river. During the late 1980s, older (lake-age 6-7) Skamania fish were apparent in catch records (Brazo 1991). These were not present in our data, suggesting that increased fishing mortality rates in Lake Michigan do not permit survival to trophy size.

Population characteristics

Observed lake ages at maturity in the St. Joseph and Grand rivers were typical for Little Manistee (2.8) and Skamania (3.5) steelhead in Lake Michigan waters (Brazo 1992; Schneider 1992; Seelbach 1993). Little Manistee fish reflected the maturity schedule of the parent feral stock (Seelbach 1993), while Skamania fish matured later, as selected to (Fielder 1987). Interestingly, Little Manistee fish in Lake Erie matured much earlier (at lake age 1.8) than expected. This is a typical pattern for steelhead and rainbow trout in Lake Erie (Wenger et al. 1985; Kayle and Hillman 1991; R. Kenyon, Pennsylvania Fish Commission, 1994, personal communication). Such a shift in maturity schedule is the result of either increased growth and gonad production by younger fish or increased mortality on older fish. As growth is not higher than in Lake Michigan, we suspect that steelhead experienced higher than normal adult mortality in Lake Erie. This is supported by our finding of low survival to repeat spawn for Huron River fish. Unusual adult mortality might be related to sportfishing, commercial fishing, or natural mortality rates. An open lake sportfishery exists (Kayle and Hillman 1991; R. Kenyon, Pennsylvania Fish Commission, 1994, personal communication), however, fishing mortality is probably no higher than on Lake Michigan (where adult survival is fairly high). Natural mortality, perhaps due to thermal stress, may be high in Lake Erie, especially in the warmer western basin. We observed "stress" checks on the scales of 38% of the lake-age-1 steelhead returning to the Huron River (Figure 16). These were indistinguishable from spawning checks; however, they were laid down during the first summer in the lake, and clearly were not spawning checks. These checks have not been seen on steelhead scales from Lake Michigan (this study; Seelbach 1993) or Lake Superior (Seelbach and Miller 1993).

Growth data were consistent with other studies of Little Manistee and Skamania steelhead in Lake Michigan (Seelbach 1989; Brazo 1992; Schneider 1992; Seelbach 1993). Reported lengths at age have not varied much between strains, rivers, or years. Lengths at age of Little Manistee fish in Lake Erie were similar to those for Lake Michigan. Length-weight regressions for both lakes were similar to those reported for Lake Michigan during the early 1980s by Seelbach (1989) and Seelbach (1993).

Sex ratios were close to the expected 50:50 for all Little Manistee groups. Seelbach (1993) reported that in the feral stock, males were favored in fall and females in spring, but that the overall ratio for returning fish was about 50:50. However, overall sex ratios favored females for returning Skamania steelhead, as has been observed in Indiana (Brazo 1992) and Wisconsin (Schneider 1992).

Implications

Stocking hatchery steelhead smolts of the Little Manistee strain can provide consistent returns and sustain valuable sportfisheries in warmwater tributaries of the Great Lakes. Survival in Lake Michigan is typically very high and large populations of returning adults can be created. Annual returns should be expected to fluctuate by a factor of 2-4 times due to environmental variation. Homing to stocking rivers and sites is quite accurate, but an adequate imprint is required for upstream migration.

Survival and returns appeared to be substantially higher for larger smolts. This hypothesis should be directly tested by monitoring the returns of matched groups of different-sized stocked smolts.

Survival and returns from Lake Erie are much lower and may be affected by walleye predation or environmental stress. Studies of the energetics of steelhead in Lake Erie are needed to determine whether this environment limits longevity and production. Either large runs of steelhead or proximity to large urban populations encourage substantial amounts of fishing effort. Increasing the number of smolts stocked into the Huron River would likely increase both annual harvest and catch rate to levels closer to those seen on Ohio streams (20,000 smolts were stocked annually in the Huron River, while nearly 100,000 smolts are stocked annually in each Ohio stream; Kayle and Hillman 1991).

Our findings suggested a direct tradeoff between high mortalities of smolts emigrating through downriver reaches and good imprinting for upstream returns. Peck (1971) and Johnson (1993) did find that predation on smolts can be minimized when stocking coincided with inshore spawning movements of alternate prey (such as alewife *Alosa pseudoharengus*). Studies of the feeding ecology of downriver predators on smolts and alternate prey are needed. In any case, we suggest that the benefits of meeting management goals of (1) creating specific upstream fisheries and (2) minimizing straying to non-target streams typically outweigh the costs of smolt mortality, and thus river mouth stocking sites are a poor option.

Stocking of Little Manistee steelhead over a 25-year period has allowed the development of self-sustaining, naturalized steelhead populations in some coldwater tributaries of the study rivers. Peck (1994) documented a similar process in a tributary of Lake Superior. Wild production in the St. Joseph and Grand rivers currently supports only a small fraction of adult runs, but habitat enhancement or opening of new stream reaches now blocked by dams could significantly increase production.

Skamania steelhead provide some options for enhancement of steelhead fisheries under certain conditions. Skamania fish offer some combination of increased smolt survival and/or increased vulnerability to open water fisheries--either way relatively more steelhead are harvested in the open water. An unbiased assessment of steelhead populations in Lake Michigan in comparison with catch surveys would clarify the vulnerability of various strains to open-water angling. Skamania steelhead mature 1-2 years later than most other steelhead strains and thus reach large size (especially if not heavily exploited prior to maturity). Skamania steelhead also offer an extension of the stream fishing season into the summer months (typically July through September). However, potential negative impacts of introducing this exotic strain also need to be considered. Skamania steelhead may potentially impact feral steelhead or other fishes by competing for limited food, spawning habitat, or rearing habitat; or by interbreeding with feral steelhead in the stocked or other rivers (Chilcote et al. 1986; Fielder 1987; Steward and Bjornn 1990; Krueger and May 1991; Krueger et al. 1994). In addition, Skamania smolts ideally should be stocked into coolwater or coldwater rivers. When summer temperatures rise, Skamania steelhead congregate at the mouths of cooler tributaries and often exibit signs of physiological stress. Guidelines for the introduction of exotic fishes provided by the American Fisheries Society (Kohler and Courtenay 1986) should be followed closely when considering use of this strain. These guidelines provide for an assessment of both the benefits and risks of the proposed introduction, and for localized testing prior to widespread introductions.

The cause of high mortality rates observed for Skamania smolts stocked at upriver Indiana sites was unclear, as these groups differed from the downstream Arden Pond groups in several important ways: stocking date, smolt size, and exposure to turbines. Controlled studies of the effects of these variables are needed to understand and minimize mortalities on stocked smolts. Turbine mortalities should be minimized wherever possible.

With recent development of upstream passage at dams for adult steelhead comes the problem of downstream passage for post-spawning adults returning to Lake Michigan. The percent of repeat spawners seen in this study was lowest (15%) in the Grand River, where many spawners ascend fish ladders at one or more dams. The abundance of repeat spawners in the St. Joseph River should be monitored for effects of increased dam passage.

Acknowledgments

Many persons contributed to this project. J. Copeland and personnel of the Wolf Lake State Fish Hatchery fin-clipped and tagged MDNR steelhead smolts. Personnel of the Bodine State Fish Hatchery fin-clipped IDNR steelhead smolts. D. Anson, A. Hilt, D. Johnson, J. Leonardi, and M. Thomas helped with administration and supervision of field operations. Numerous creel clerks surveyed anglers and collected data. J. Clevinger, Sr. was responsible for counts and data collection at the Berrien Springs dam. D. Borgeson, S. Markham, T. Somers, and S. Vanderlaan read all scales and managed databases for samples taken from the rivers. R. Hay and J. Sapak provided databases for samples taken from the open lake fishery. P. Gelderbloom and J. Clevinger, Jr. provided the database for coded-wire tags. G. Rakoczy and R. Svoboda analyzed the creel census data.

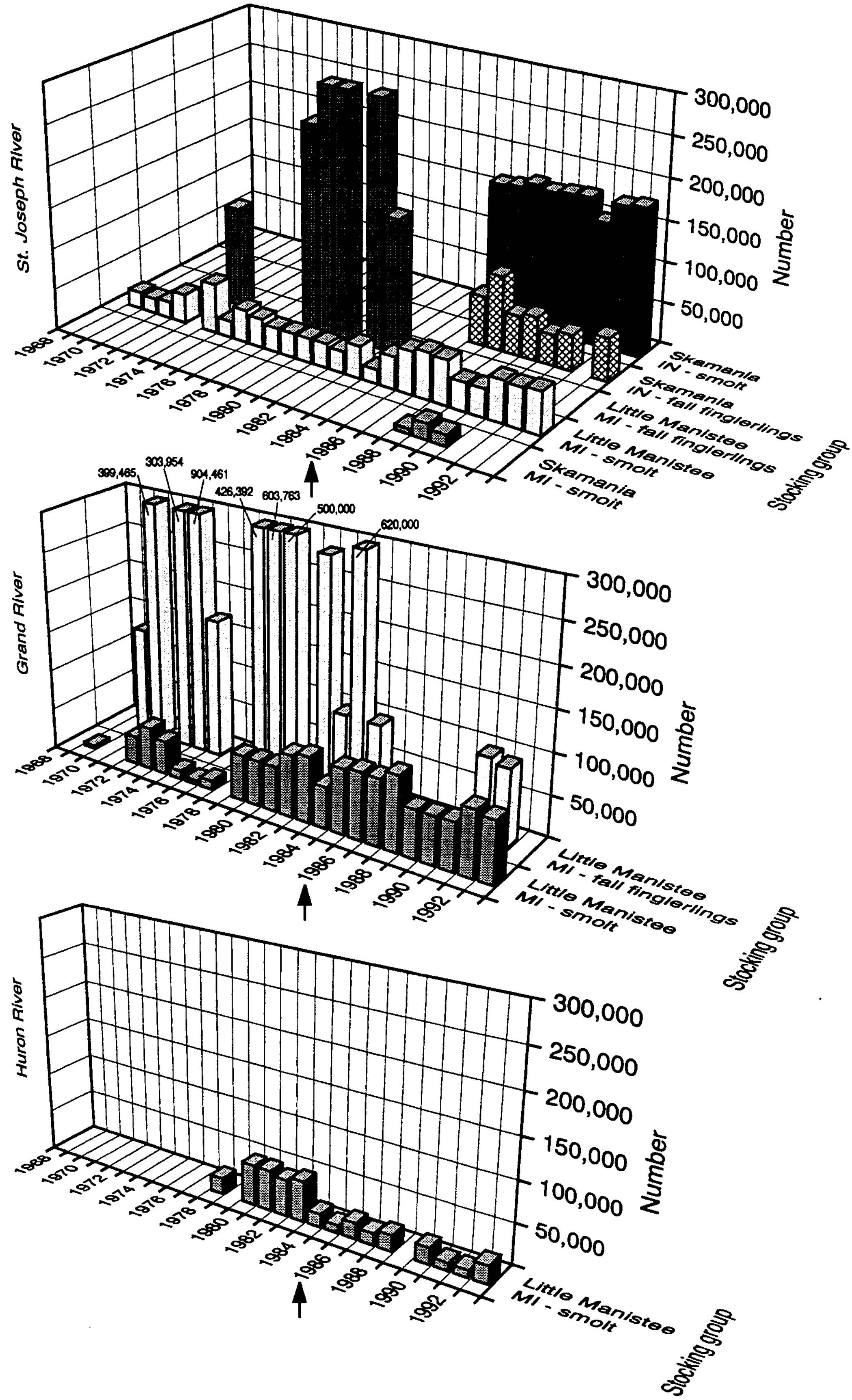

Figure 1.—Numbers of hatchery-raised steelhead stocked into the St. Joseph, Grand, and Huron rivers during 1968-93, by strain and age. The change in 1986 to stocking yearling smolts (from yearling parr) is shown by an arrow.

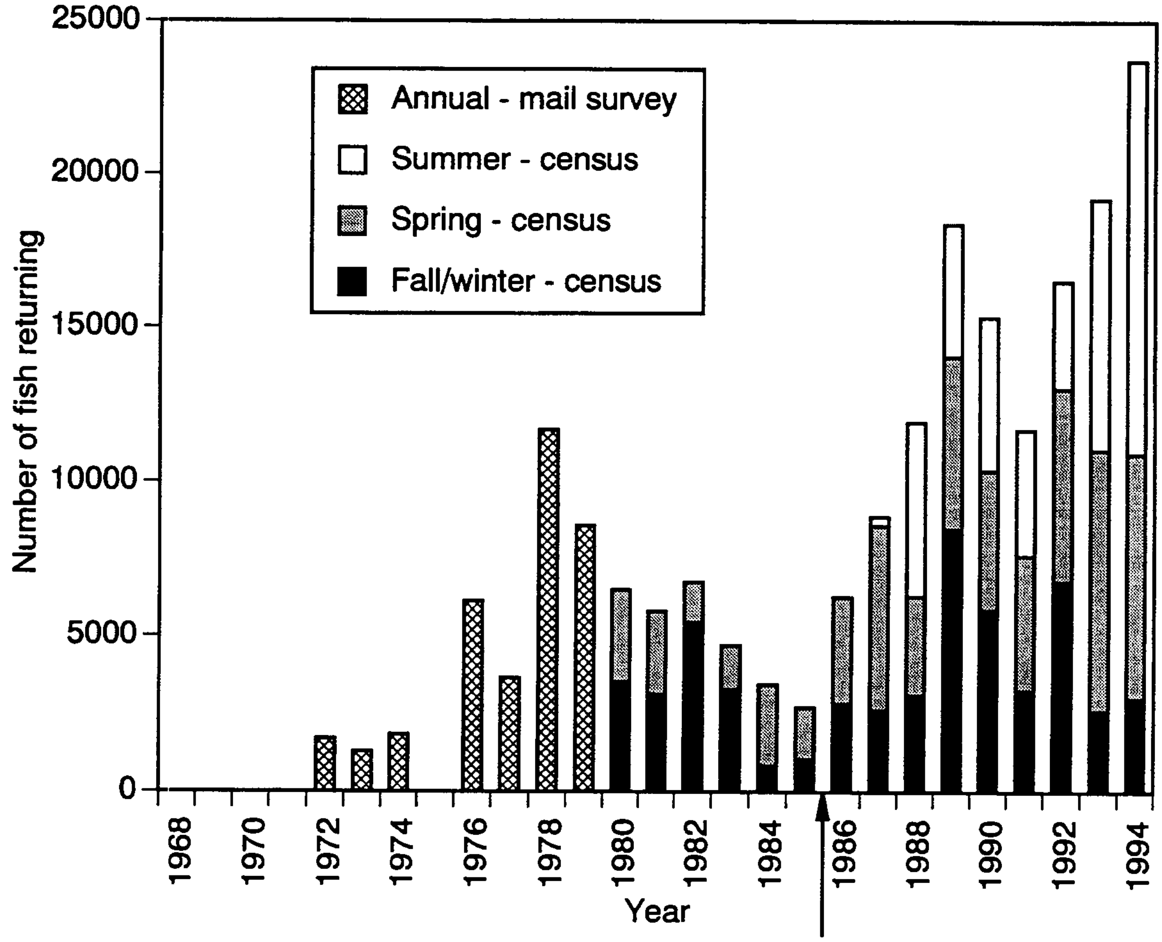

Figure 2.—Minimum adult steelhead returns to the lower St. Joseph River. Beginning in 1980 returns were estimates of harvest (based on creel census) from Berrien Springs dam downstream to the river mouth plus counts of fish ascending the Berrien Springs fish ladder. Total returns prior to 1980 were estimates of harvest from a statewide mail survey, adjusted according to overlapping data in 1979-80. The change in 1986 to stocking yearling smolts (from yearling parr) is shown by an arrow.

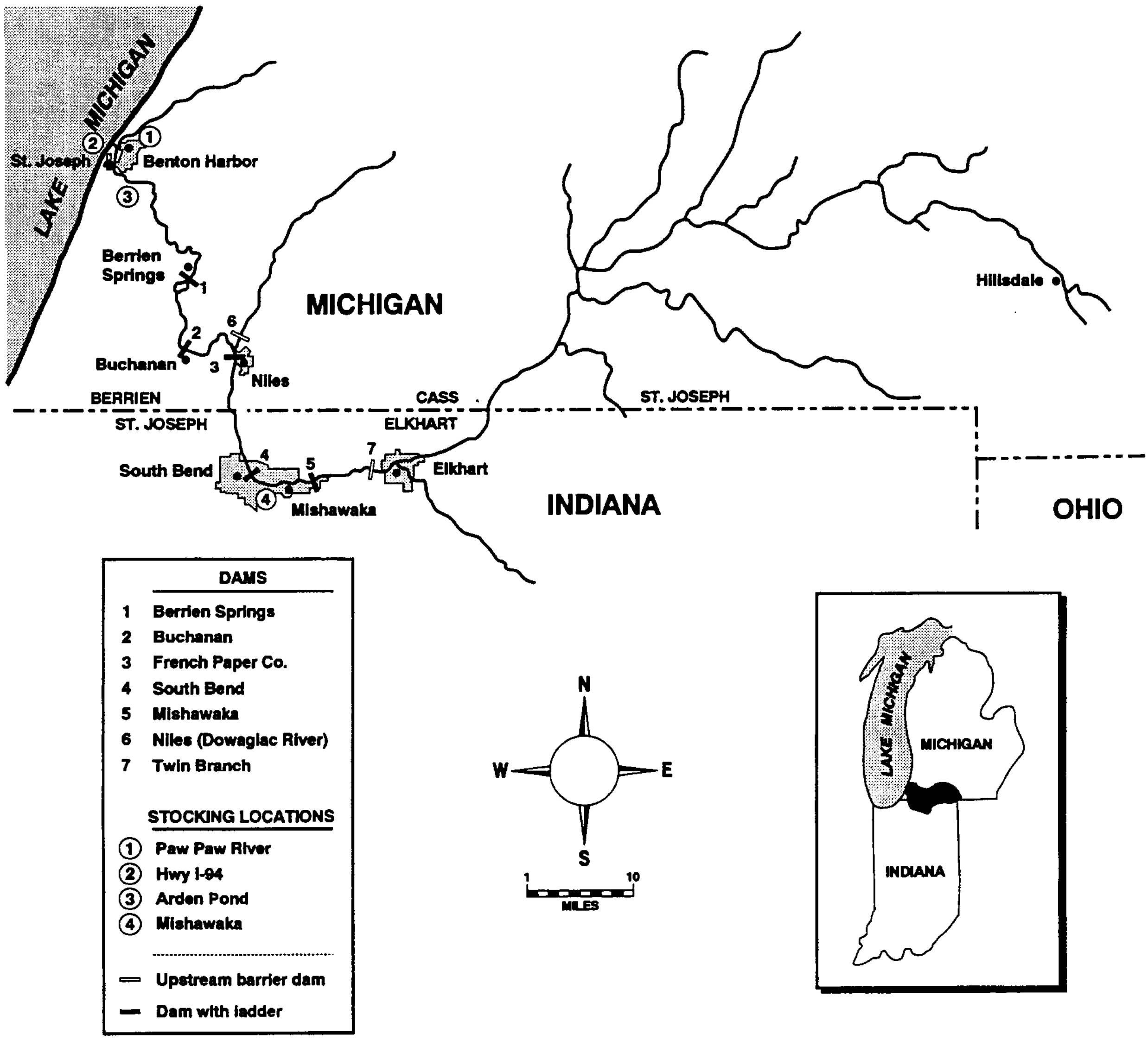

Figure 3a.—Location of the St. Joseph River in southern Michigan. Shown are major cities, stocking locations, fish ladders, and barrier dams.

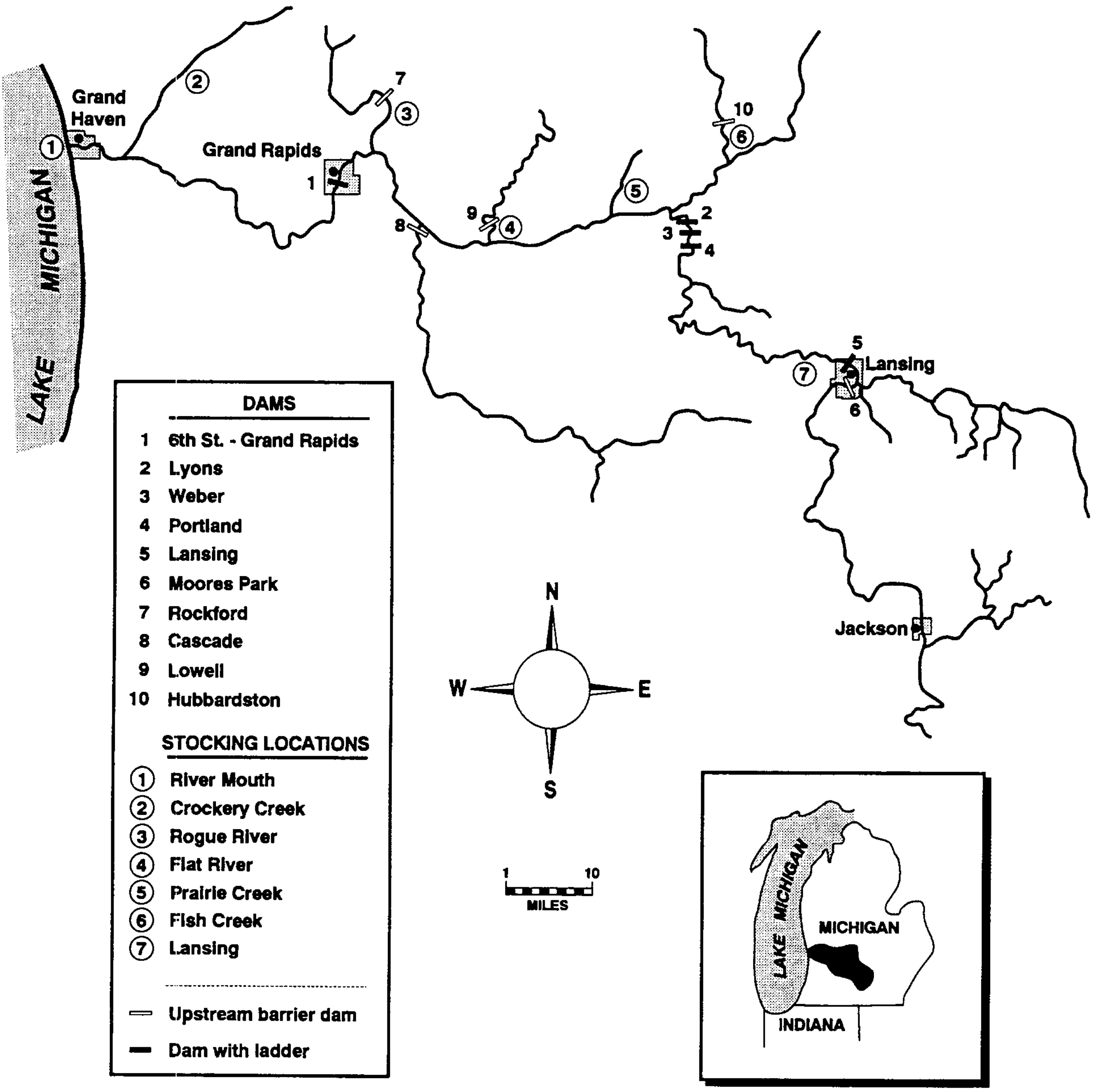

Figure 3b.—Location of the Grand River in southern Michigan. Shown are major cities, stocking locations, fish ladders, and barrier dams.

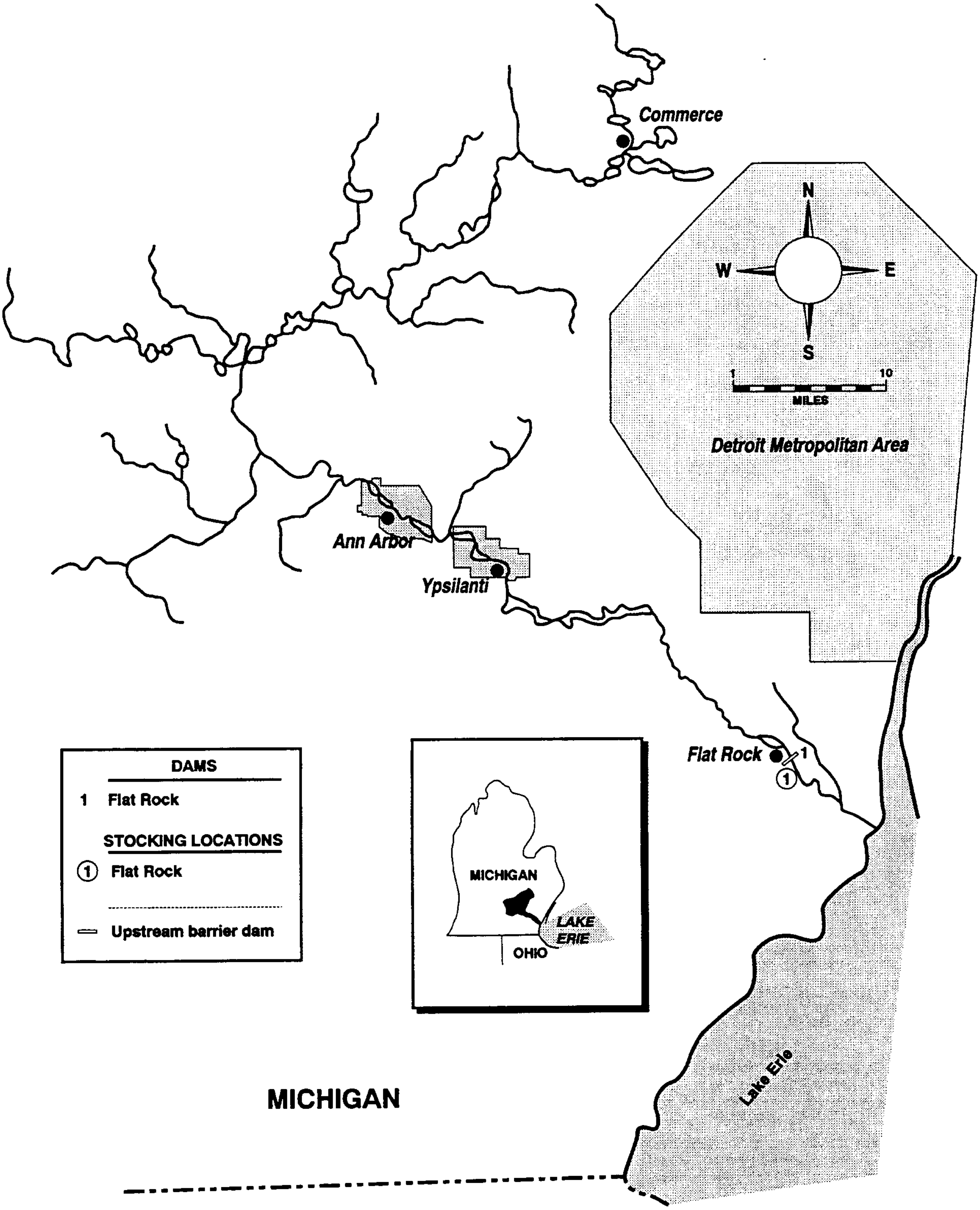

Figure 3c.—Location of the Huron River in southern Michigan. Shown are major cities, stocking locations, and barrier dams.

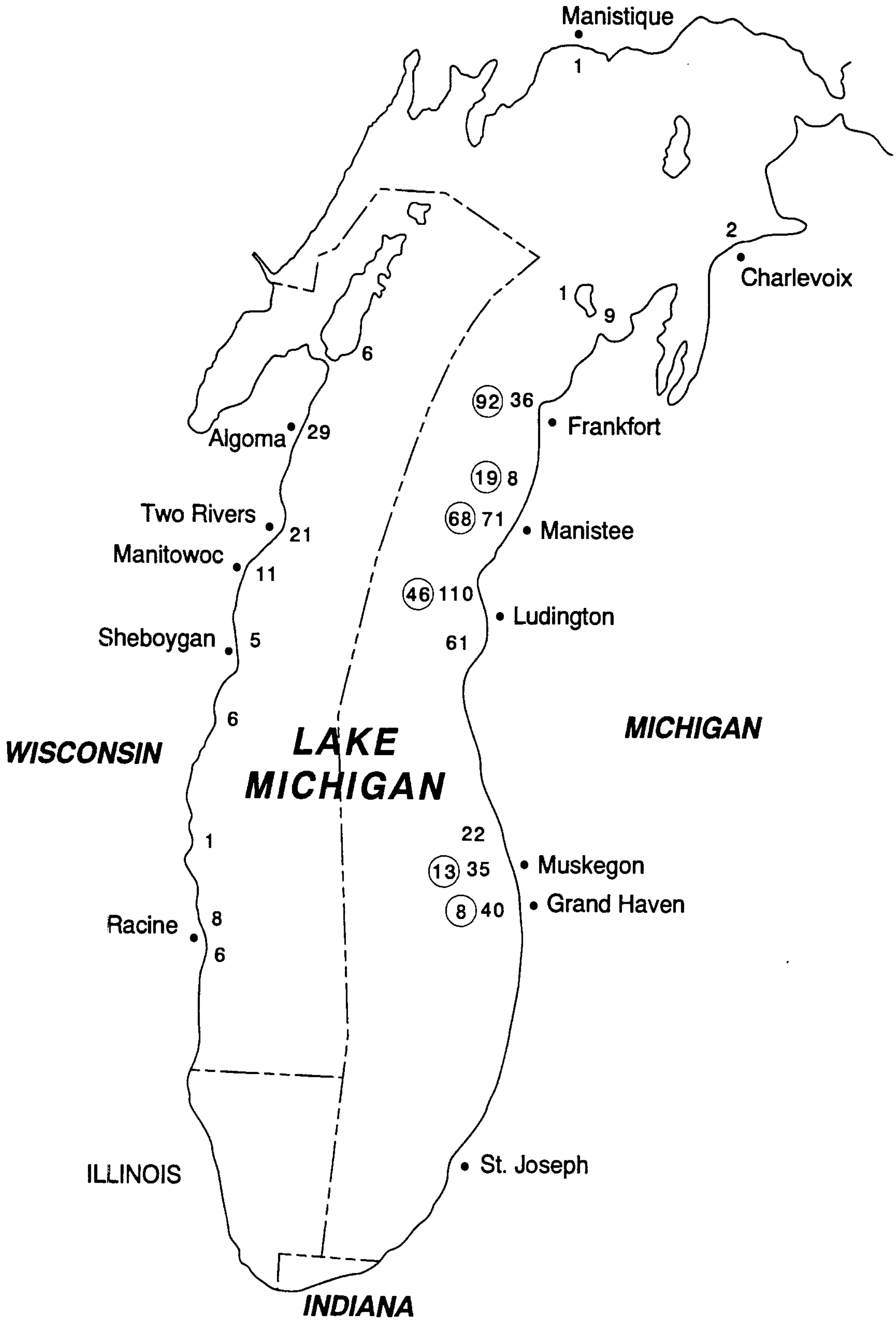

Figure 4.—Summer distribution in Lake Michigan (1988-94) of steelhead stocked as smolts in the St. Joseph and Grand rivers during 1988-90. Indiana fish are shown circled. Collection of Indiana fish (marked with a fin clip, as opposed to a coded-wire tag) was limited to Michigan waters.

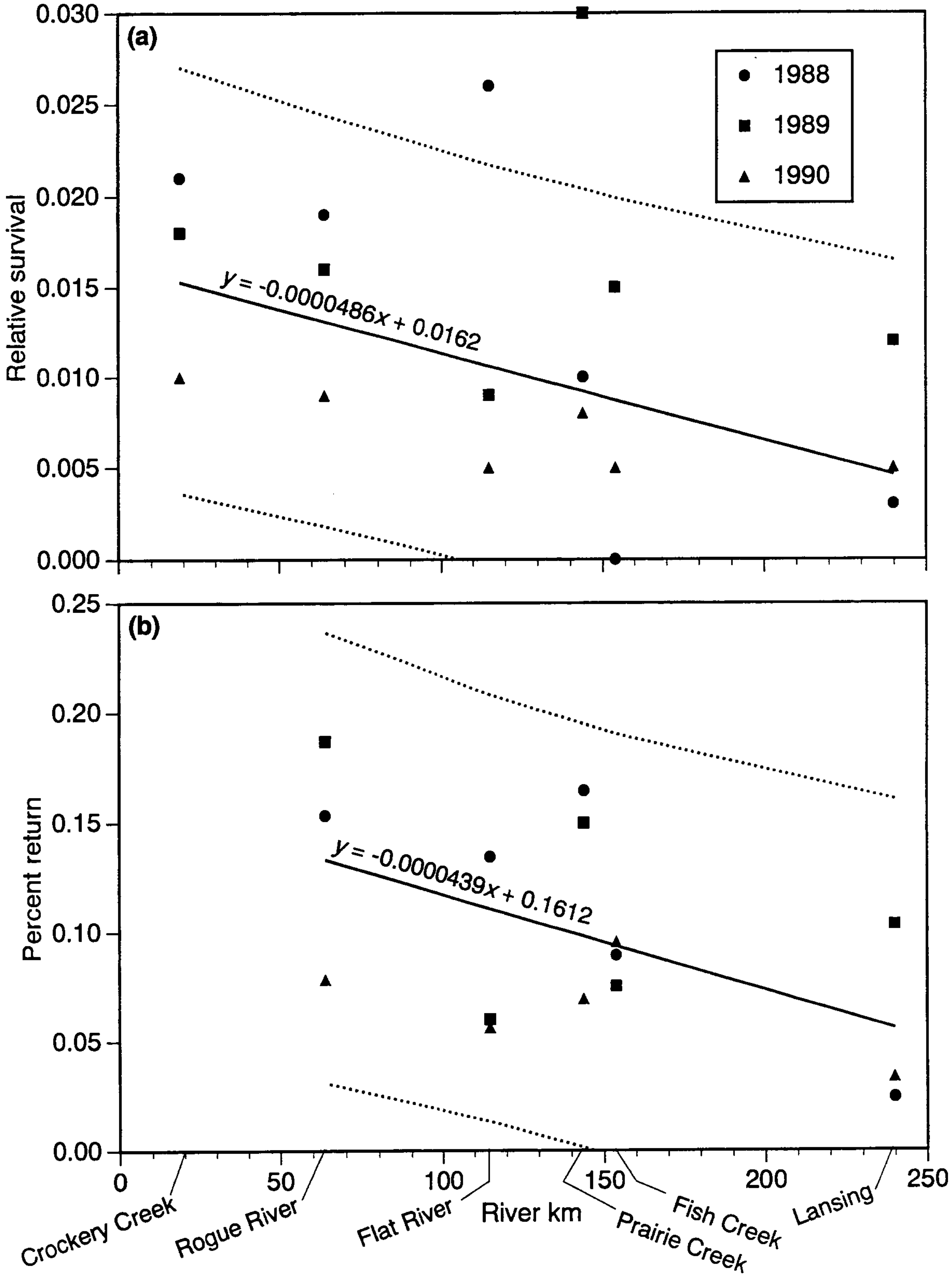

Figure 5.—Relationship between the distance upstream of stocking location, and relative survival to (a) the open-lake catch and (b) percent returns to the 6th St. dam for Little Manistee strain steelhead smolts stocked at various locations within the Grand River system, 1988-90. In each figure the regression line is shown as a solid line and 2SE as dotted lines.

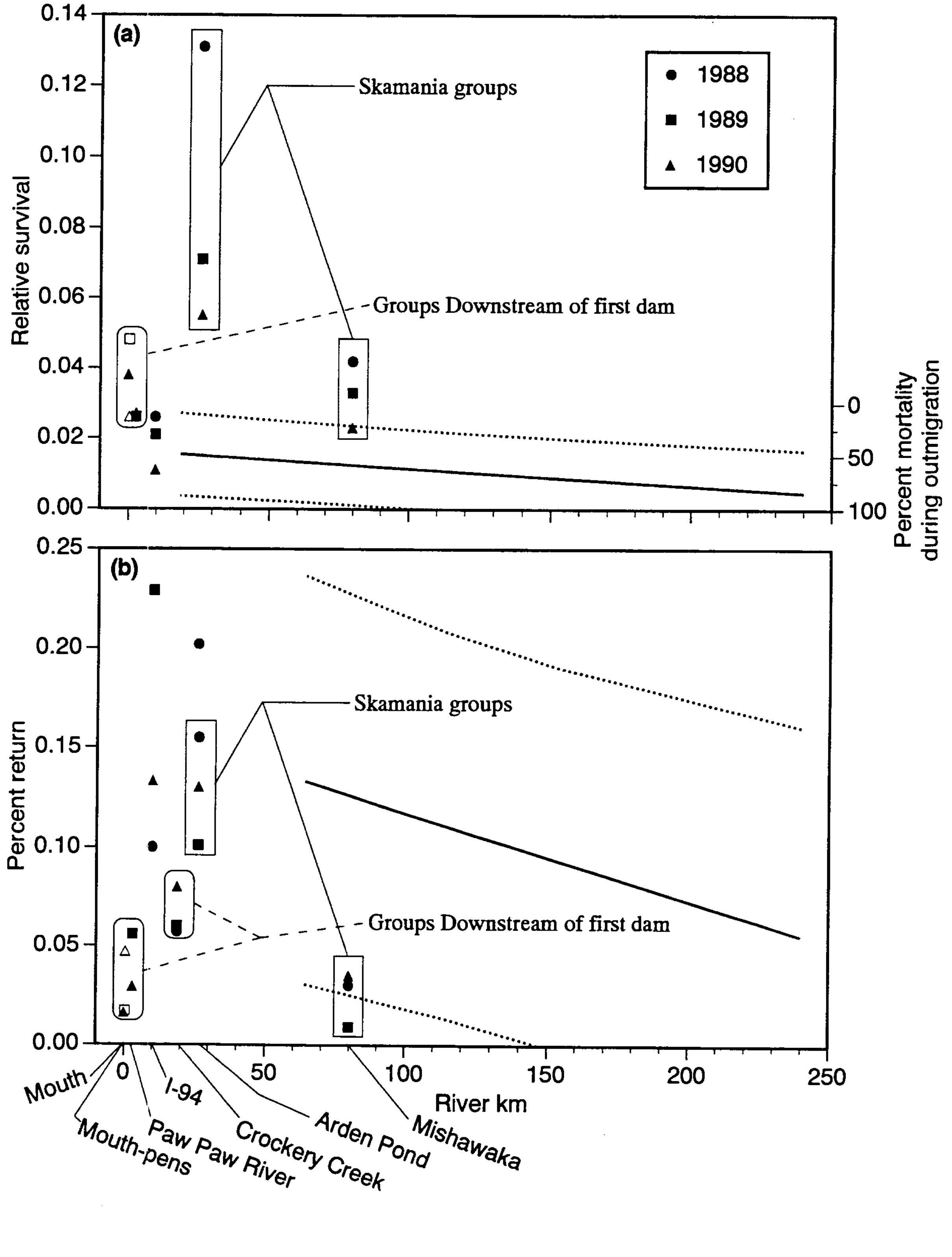

Figure 6.—Comparison between relative survival to (a) the open-lake catch and (b) percent returns to the first upstream dam for steelhead stocked in 1988-90 at selected locations, and the Grand River models from Figure 5 (shown as a solid and dotted lines). Mouth-pens are shown as open symbols.

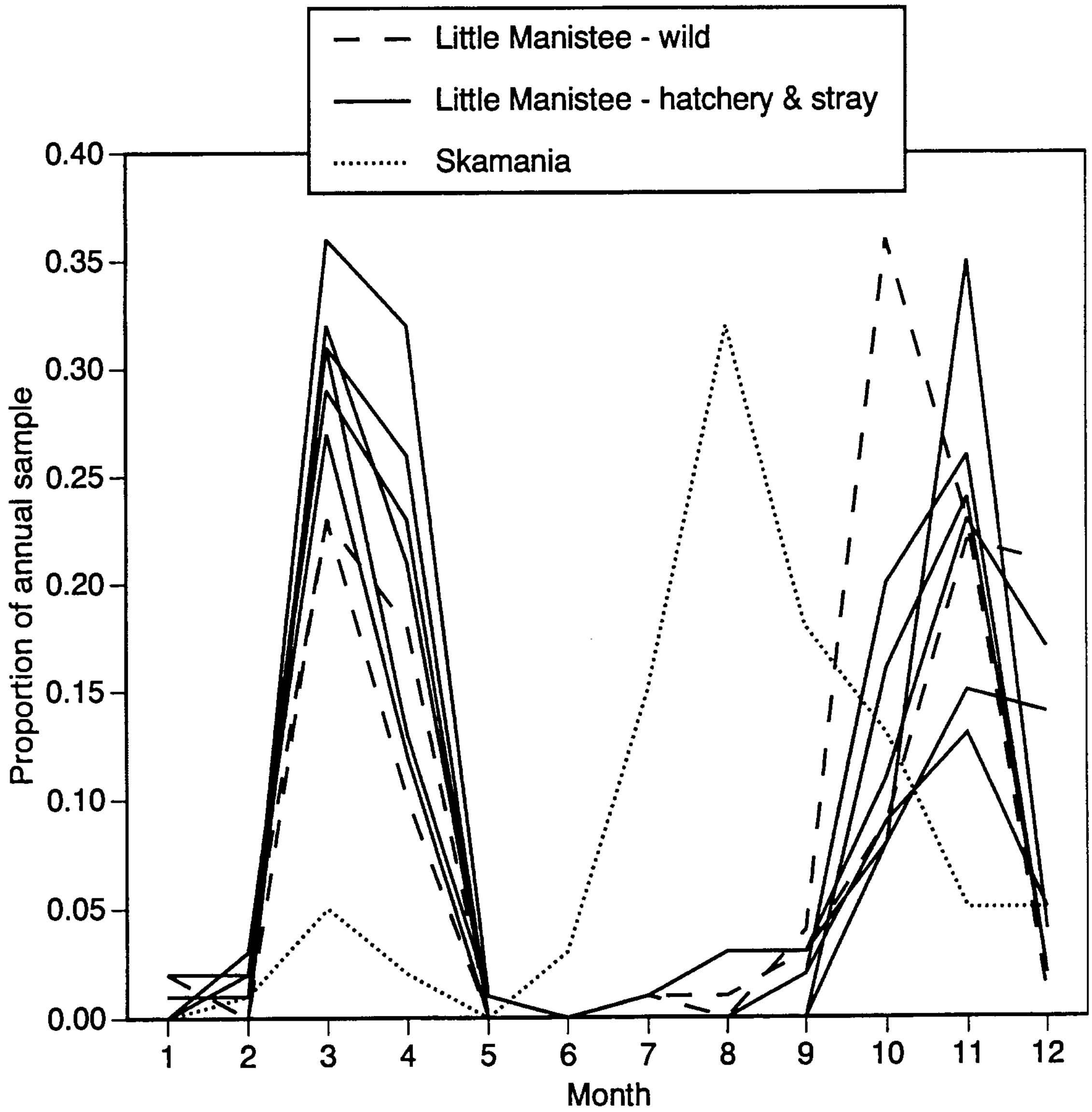

Figure 7.—Migration timing of steelhead groups returning to the St. Joseph, Grand, and Huron rivers during 1989-94; shown as the proportion of annual samples of the harvest collected each month.

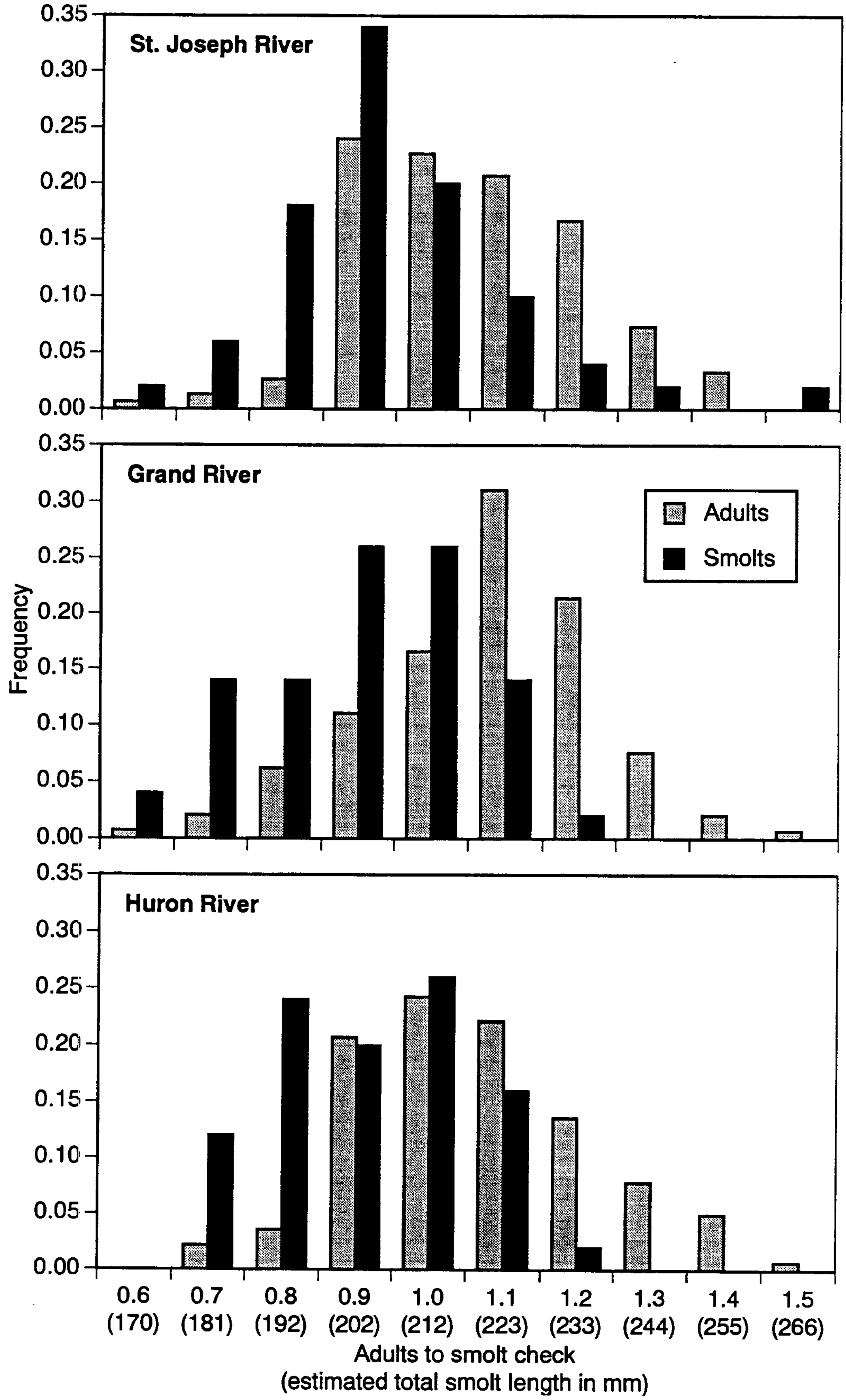

Figure 8.—Comparison of frequency distributions of radii to smolt check between smolt and adult scales in the St. Joseph, Grand, and Huron rivers, 1988-94.

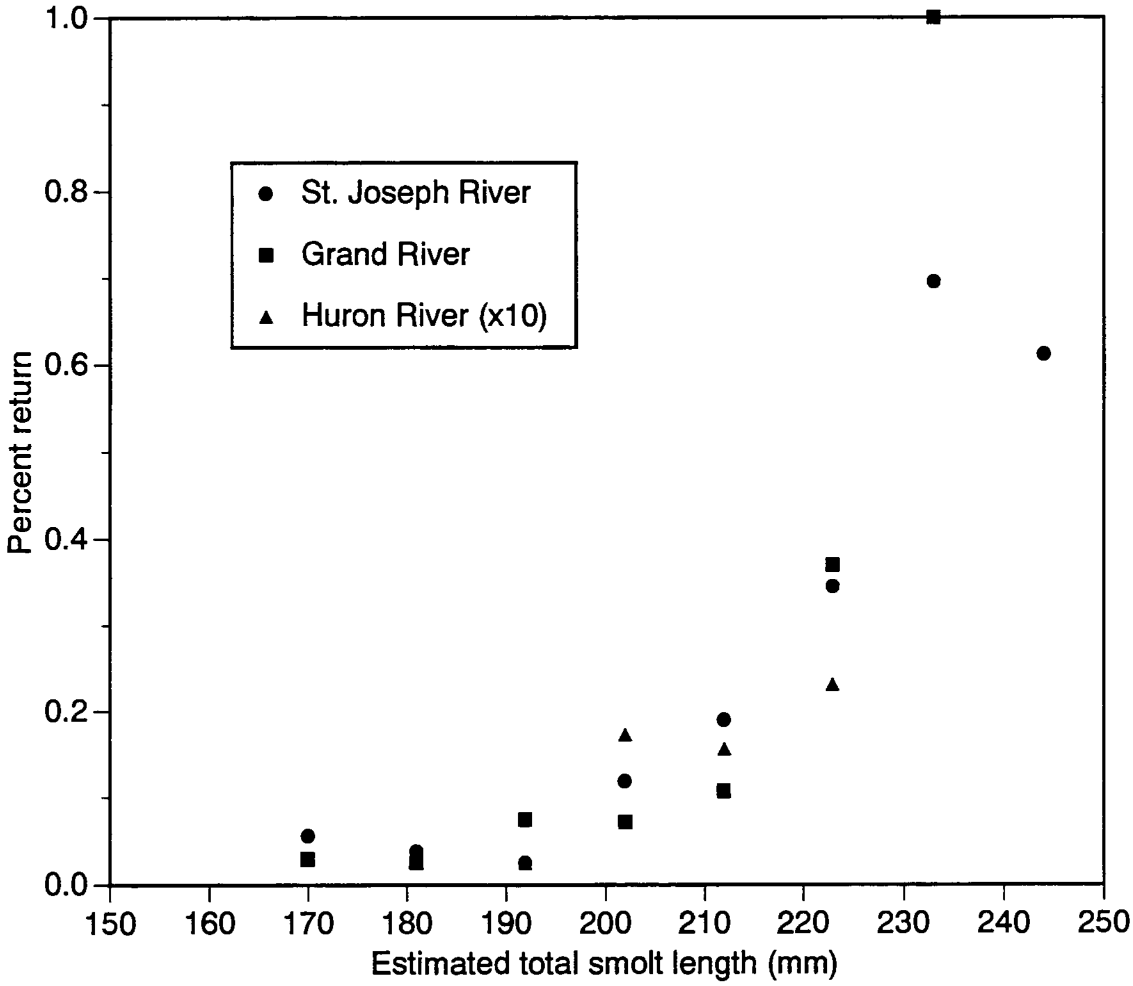

Figure 9.—Percent returns to the first dam, by total length (mm), for steelhead smolts stocked into the St. Joseph, Grand, and Huron rivers, 1988-90.

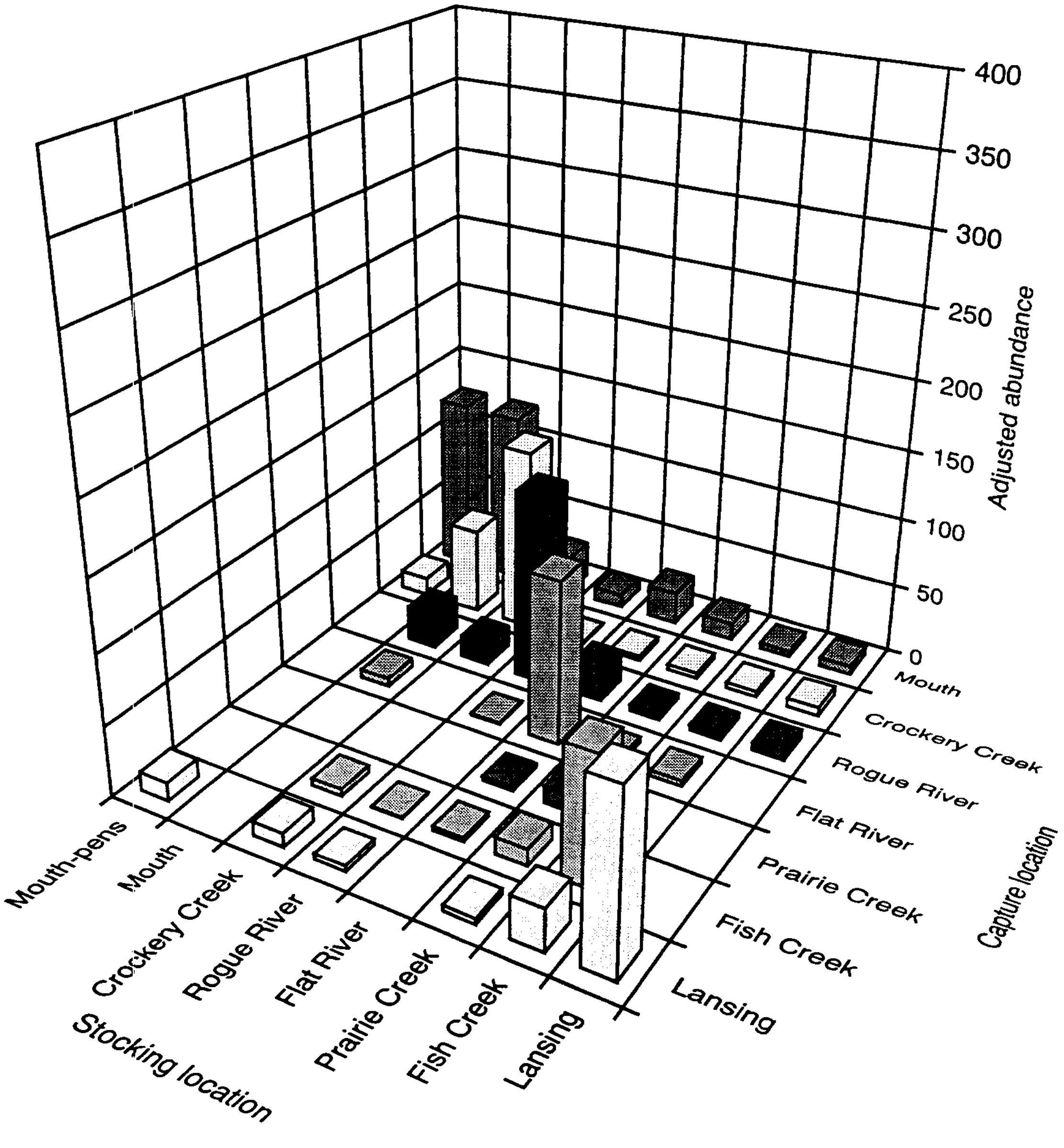

Figure 10.--Homing of Little Manistee strain steelhead to stocking sites within the Grand River system. Higher values of adjusted abundance indicate stronger homing.

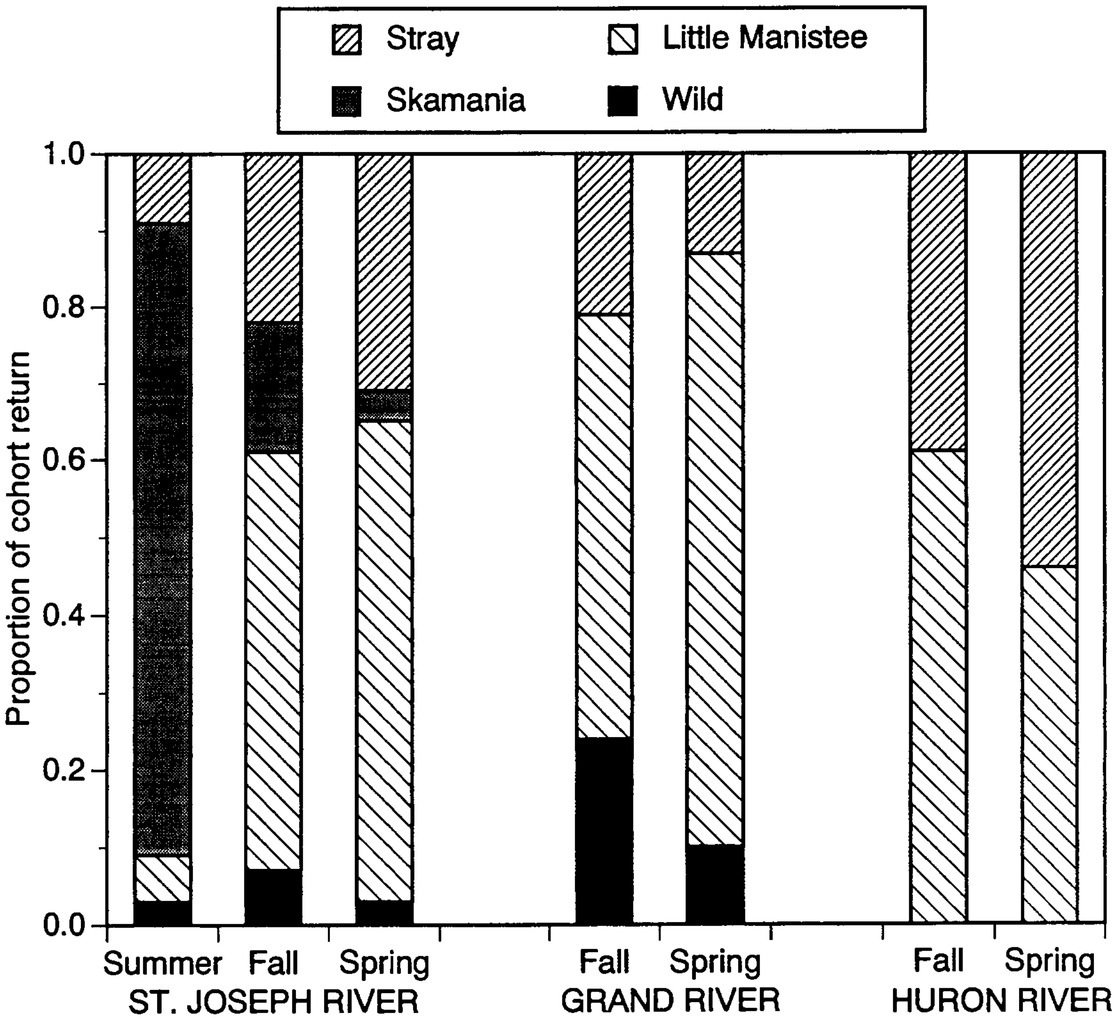

Figure 11.—Percent composition of steelhead returning from the 1988-90 smolt cohorts to the St. Joseph, Grand, and Huron rivers, by group of origin.

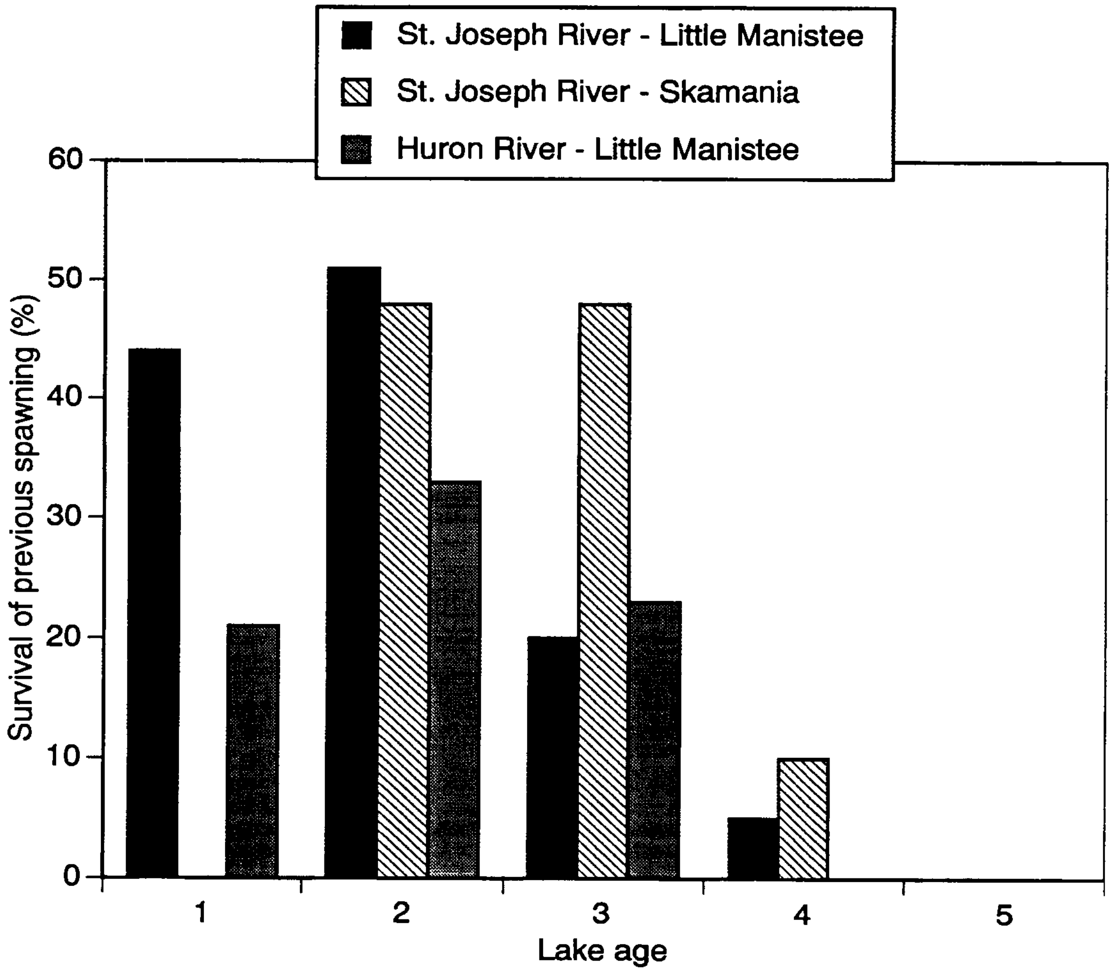

Figure 12.—Percent of hatchery steelhead returning to the St. Joseph, Grand, and Huron rivers that survived previous spawning; by lake age and strain.

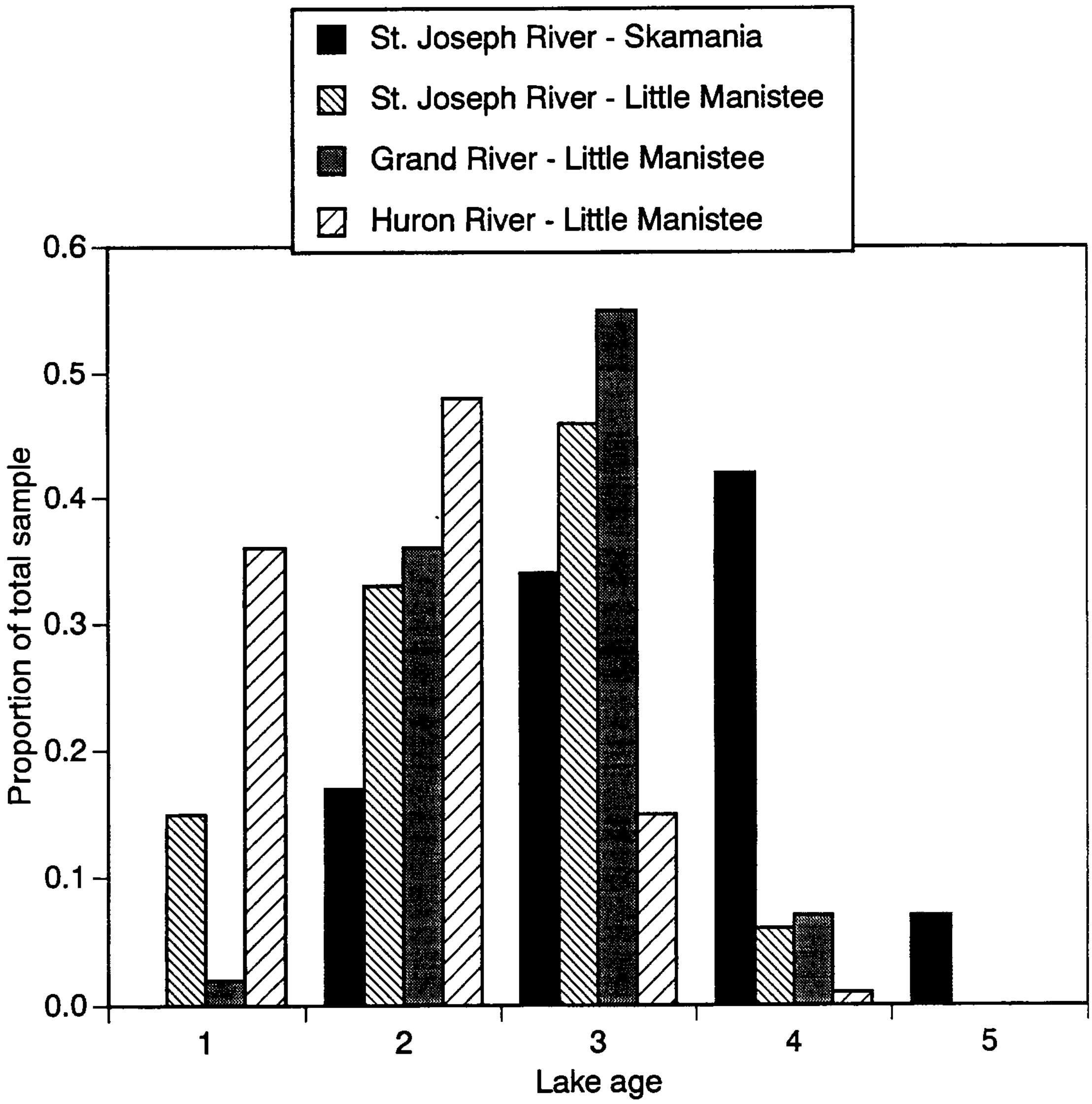

Figure 13.—Proportions of samples of hatchery steelhead returning at different lake ages to the St. Joseph, Grand, and Huron rivers during 1989-94; by strain.

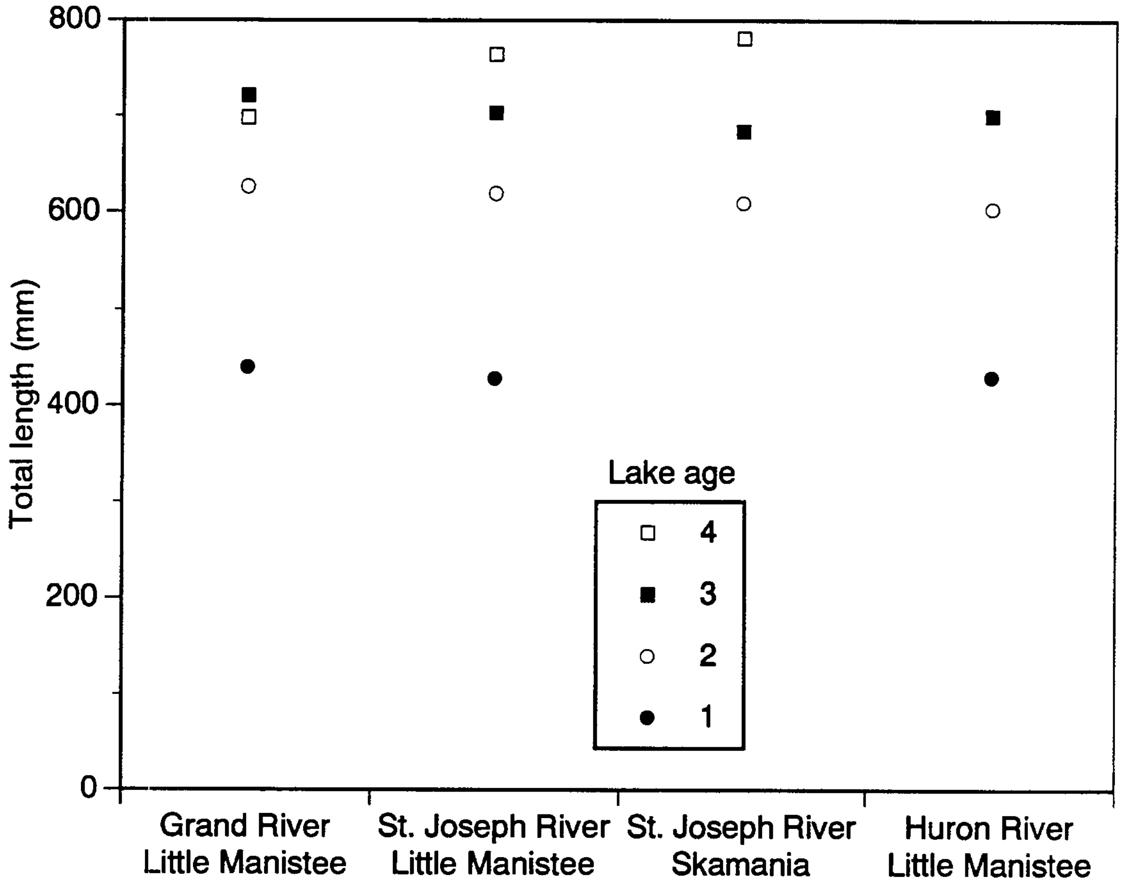

Figure 14.—Mean total length (mm) at lake age for male jack (lake-age 1) and female hatchery steelhead of 2 strains returning as maiden spawners to the St. Joseph, Grand, and Huron rivers during 1989-94.

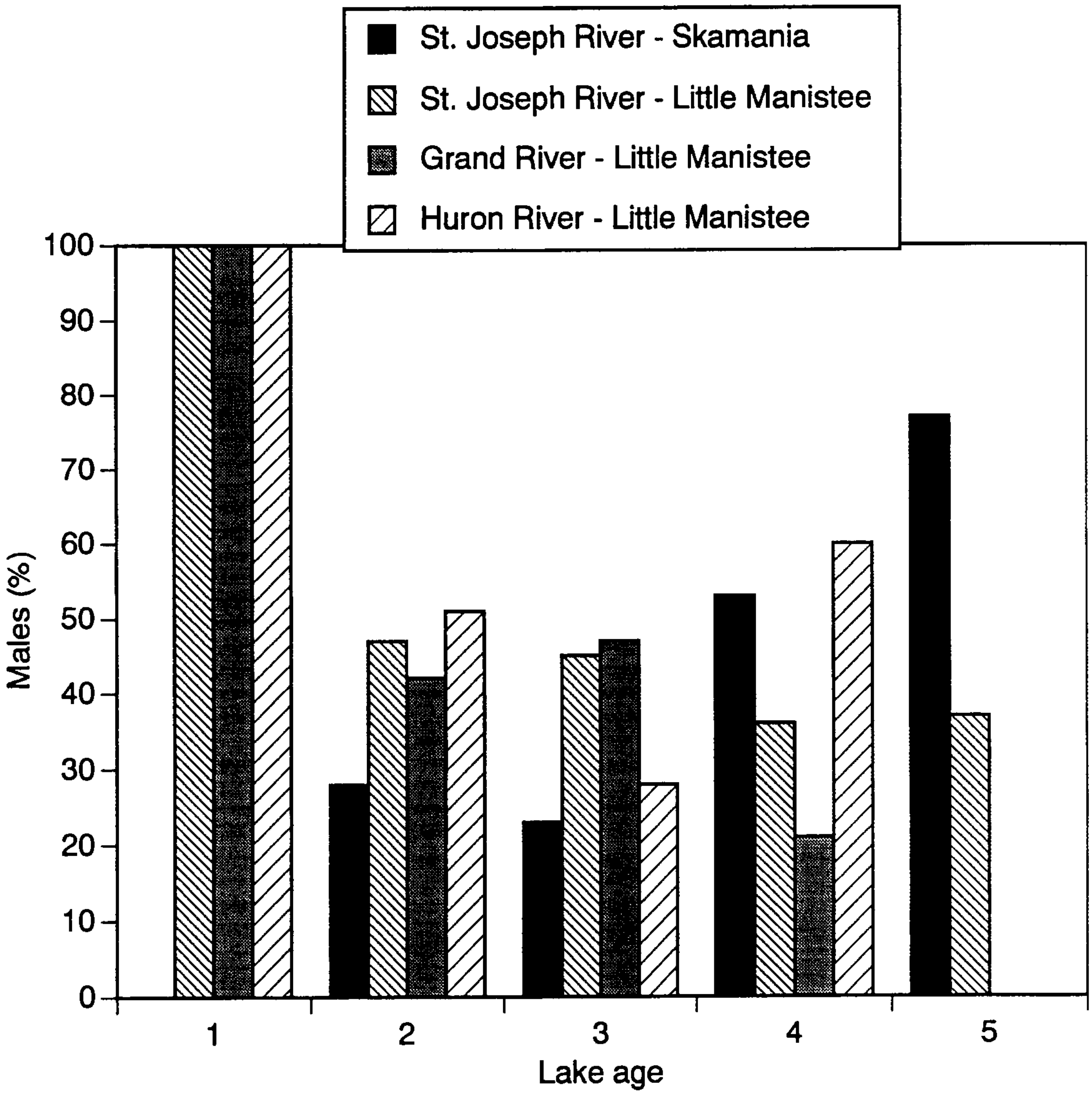

Figure 15.—Percent males in samples of hatchery steelhead returning to the St. Joseph, Grand, and Huron rivers during 1989-94; by lake age and strain.

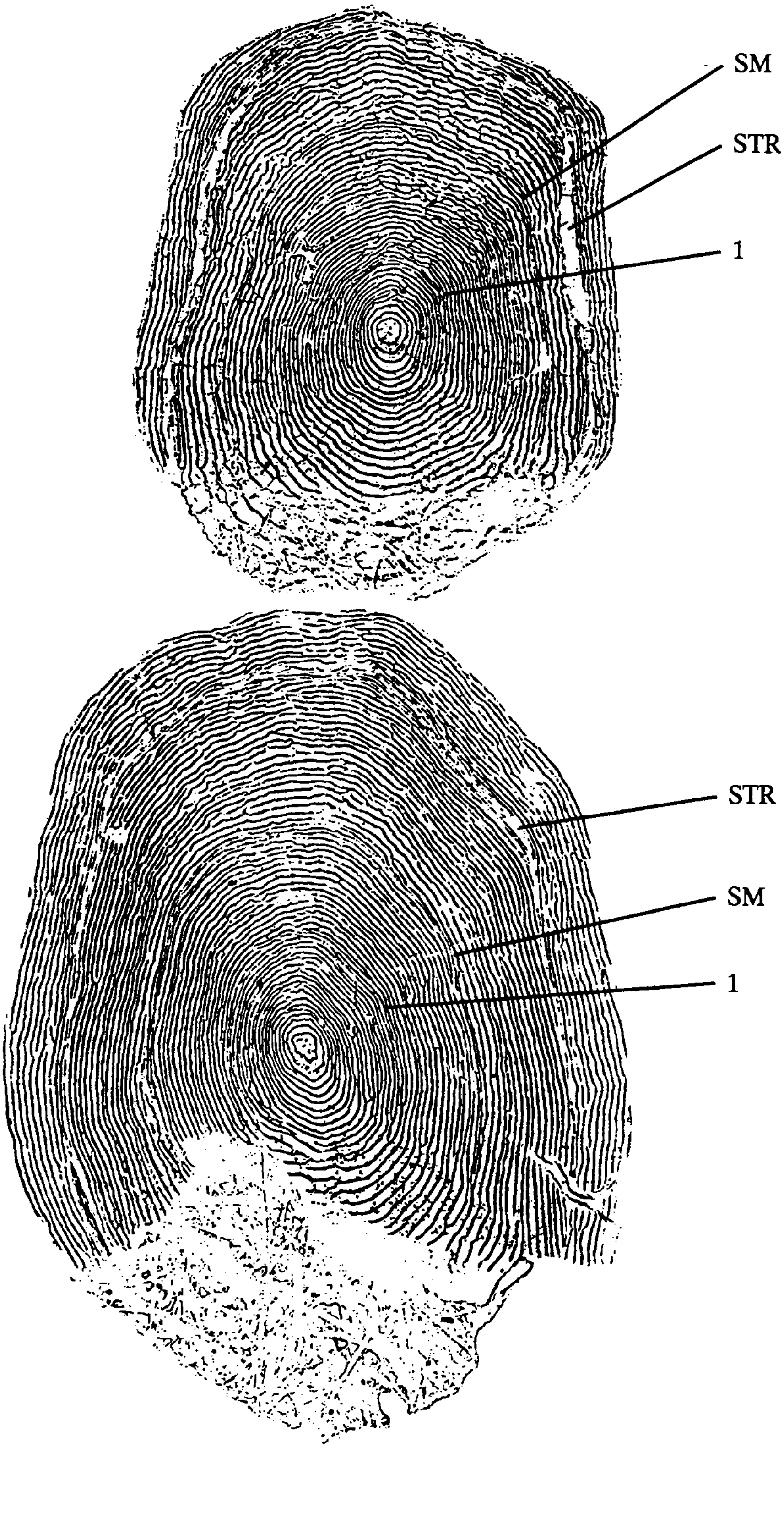

Figure 16.—Scale of an known-age 1.1 hatchery steelhead returning to the Huron River from Lake Erie showing a stress check (shown as "STR") during the first summer in the lake. Also shown are the first annulus (as "1") and the smolt check ("SM").

Table 1.—Number and mean length of marked hatchery steelhead stocked at various locations in the St. Joseph, Grand, and Huron rivers 1986-90. All fish were yearling smolts except where noted. Mean total length shown by [ ] was estimated from mean weight at stocking; mean total length shown by {} was estimated from a subsample (N=200).

Strain and stocking location	Number stocked [mean total length in mm] 1988	1989	1990
Little Manistee			
St. Joseph River			
Berrien Springs	50,103 [191] {196}	35,172 [196] {210}	34,558 [191] {189}
Arden Pond	5,688 {190}*		
Paw Paw River		8,669 [196]	7,013 [185]
Grand River			
Lansing	19,990 [197]	10,111 [198]	10,647 [179]
Fish Creek	10,029 [185]	4,974 [200]	5,204 [184]
Prairie Creek	5,037 [191]	2,994 [197]	3,066 [184]
Flat River	9,766 [189]	4,988 [194]	5,050 [182]
Rogue River	40,069 [195] {199}	22,357 [196] {197}	20,845 [190] {188}
Crockery Creek	7,000 [192]	4,028 [198]	3,999 [181]
Mouth			5,039 [185]
Mouth pens		9,215 [190]	5,086 [178]
Huron River			
Flat Rock	19,975 [188] {196}	17,993 [196] {199}	20,098 [189] {188}
Skamania			
St. Joseph River			
Arden Pond	6,097 {190}*	19,334 {224}	13,806 {233}
Mishawaka	172,262 [195]	175,786 [183]	176,810 [185]
Mishawaka (fall fingerling)	48,905 [133]	53,883 [140]	38,282 [148]

*Represents combined groups.

Table 2. Relative survival to the summer open-lake fishery and percent returns to the first upriver dam for steelhead stocked into the St. Joseph and Grand rivers during 1988-90. Skamania steelhead are indicated by "*".

Stocking site	River km	Open-lake returns Smolt cohort			Returns to dam Smolt cohort		
		1988	1989	1990	1988	1989	1990
Grand River							
Lansing	240	0.003	0.012	0.005	0.024	0.103	0.033
Fish Cr	154	0.000	0.015	0.005	0.089	0.075	0.095
Prairie Cr	144	0.010	0.030	0.008	0.164	0.150	0.069
Flat R	115	0.026	0.009	0.005	0.134	0.060	0.056
Rogue R	64	0.019	0.016	0.009	0.153	0.187	0.078
Crockery Cr	19	0.021	0.018	0.010	0.057	0.060	0.080
Mouth	0	--	--	0.038	--	--	[a]
Mouth--pens	0	--	0.048	0.026	--	[a]	[a]
St. Joseph River							
Mishawaka	80	0.042	0.033	0.023	0.030	0.009	0.035
Arden Pond	26	0.000	--	--	0.202	--	--
Arden Pond*	26	0.131	0.071	0.055	0.155	0.101	0.130
I-94	10	0.026	0.021	0.011	0.100	0.229	0.133
Paw Paw R	3	--	0.026	0.027	--	0.056	0.029

[a] Recaptures<3.

Table 3.—Seasonal harvest, harvest rates, and angler days for steelhead fisheries on the St. Joseph and Huron rivers, for spawning cohorts 1988-94. A spawning cohort includes summer and fall migrants from the previous calendar year.

Spawning cohort	Harvest			Harvest rate			Angler hours		
	Summer	Fall-W	Spring	Summer	Fall-W	Spring	Summer	Fall-W	Spring
St. Joseph River									
1988	4,623	2,673	2,100	0.04	0.11	0.09	89,823	79,204	31,002
1989	3,450	7,480	3,935	0.04	0.07	0.04	93,723	66,635	22,003
1990	3,633	3,779	861	0.05	0.07	0.04	76,209	35,376	21,364
1991	3,481	1,626	1,242	0.04	0.07	0.05	57,686	73,334	25,787
1992	2,591	5,055	2,192	0.03	0.12	0.09	89,200	40,909	25,066
1993	6,708	1,699	1,309	0.06	0.05	0.08	111,050	32,524	17,141
1994	1,056	1,278	2,000	0.02	0.03	0.05	72,383	40,927	38,020
Huron River									
1989		225	374		0.03	0.02		8,868	16,879
1990		175	312		0.01	0.02		13,975	15,283
1991		251	210		0.02	0.02		13,384	9,993
1992		134	276		0.01	0.03		10,641	10,555
1993		398	66		0.03	0.01		12,217	10,357

Table 4. Number of adult steelhead moving upstream through the fish ladder at the Berrien Springs dam on the St. Joseph River, for spawning cohorts 1988-94.

Spawning cohort	Number of fish passing		
	Summer	Fall-W	Spring
1988	1,007	434	1,065
1989	845	980	1,659
1990	1,333	2,057	3,648
1991	607	1,624	3,101
1992	875	1,706	4,060
1993	1,468	903	7,086
1994	11,789	1,729	5,881

Table 5. Minimum returns to Berrien Springs dam of Skamania steelhead stocked in the St. Joseph River near Mishawaka, as fall-fingerling parr and smolts during 1986-90.

Smolt cohort	Fall fingerling parr	Spring smolts
1986	0.007	0.029
1987	0.015	0.023
1988	0.027	0.030
1989	0.000	0.009
1990	0.025	0.025
Mean	0.015	0.023

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