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Survival of Juvenile Lake Trout Stocked in Western Lake Huron during 1974–1992

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Abstract.—The population of lake trout *Salvelinus namaycush* in the main basin of Lake Huron collapsed in the late 1940s from the combined effects of overfishing and predation by sea lampreys *Petromyzon marinus*. Stocking juvenile lake trout has been one of the key management strategies in efforts toward lake trout rehabilitation. However, the survival of juvenile stocked lake trout has decreased over time in lakes Erie, Ontario, and Superior. We examined catch per effort (CPE) for age-5 fish divided by the number of that year-class that was previously stocked to determine whether the survival of juvenile stocked lake trout changed in Michigan waters of Lake Huron. During 1974–1992, this standardized CPE decreased significantly in the northwestern part of Lake Huron but did not change significantly in the central or southwestern parts of the lake. The trend in the northwestern part of the lake probably reflects decreasing juvenile survival attributable to increases in sea lamprey abundance. Our study suggests that stocking hatchery-reared lake trout is still a viable management option for building and maintaining an adult lake trout stock in Lake Huron.

Historically, the predominant predator in Lake Huron was lake trout *Salvelinus namaycush* (Smith 1972). The lake trout population of the main basin of Lake Huron collapsed in the late 1940s as a result of the combined effects of overfishing and mortality caused by the exotic sea lamprey *Petromyzon marinus* (Hile 1949; Berst and Spangler 1972). Lake trout rehabilitation began with tightened regulation of the commercial fishery, control of sea lamprey populations, and stocking of hatchery-reared lake trout (Eshenroder et al. 1995). Sea lamprey control was instituted for Lake Huron in 1960 (Smith and Tibbles 1980), commercial lake trout fisheries were closed in Michigan waters in 1967 (Brege and Kevern 1978), and lake trout stocking began in the northwestern part of the lake in 1972 (Eshenroder et al. 1995). Within Lake Huron, substantial commercial harvest of lake trout still occurs in Ontario waters and, in accord with agreements based on the 1836 Treaty of Washington, in northwestern Michigan waters. Sea lamprey control has been only partially effective, and sea lamprey-induced mortality is still an important factor inhibiting lake trout rehabilitation (Eshenroder et al. 1995). Rehabilitation efforts continue with sea lamprey control, limits on sport and commercial fishing, and the stocking of hatchery-reared fish. The rehabilitation goals of self-sustaining lake trout populations have not yet been reached, however, as the vast majority of the lake trout in Lake Huron are derived from hatchery sources (Eshenroder et al. 1995).

Knowledge of changes in survival from stocking to ages that contribute to harvest and spawning stock is important (Ebener 1998), because nearly all recruits are currently derived from hatchery sources in Lake Huron (Eshenroder et al. 1995). Also, stock assessment models, recently applied for lake trout in Lake Huron and elsewhere (e.g., Sitar et al. 1999), assume that recruitment to ages seen in fisheries and survey gears is proportional to numbers stocked and therefore that juvenile survival is constant. However, Elrod et al. (1993), Hansen et al. (1994), and Cornelius et al. (1995) found that prerecruit survival of stocked lake trout in Lake Ontario, Lake Superior, and Lake Erie decreased over time. Therefore, we questioned whether similar changes had occurred in Lake Huron. Our goal was to determine whether prerecruit survival (up to age 5) of the 1974–1992 year-classes of nearshore-stocked lake trout changed in the Michigan waters of Lake Huron.

Methods

Data collection.—The study area included the Michigan waters of Lake Huron, which are divided

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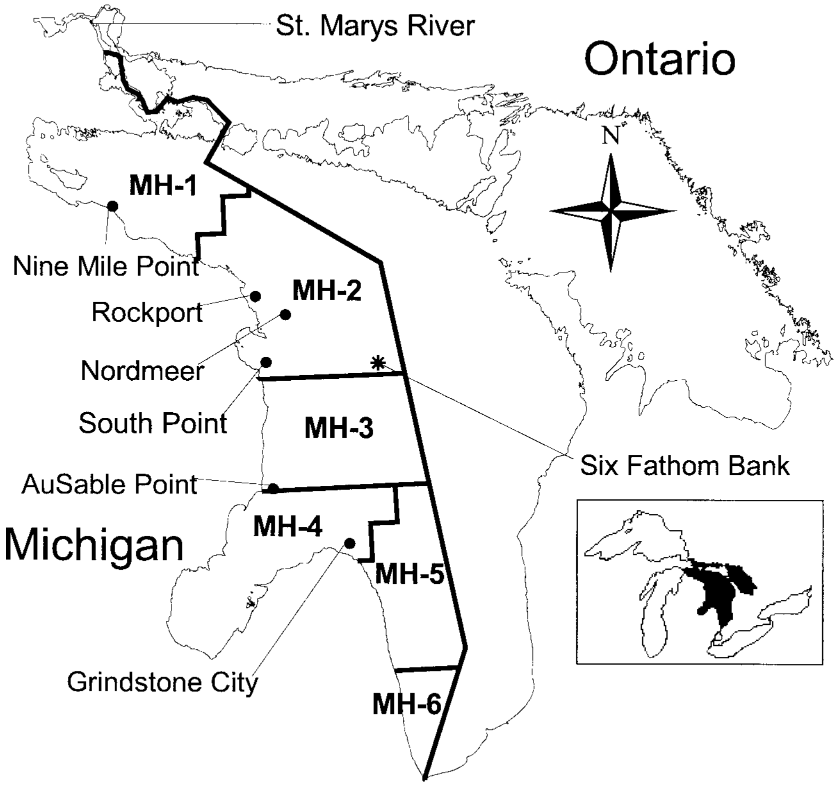

FIGURE 1.—Map of Lake Huron showing Michigan statistical districts (MH-1 to MH-6), assessment sites, and the Six Fathom Bank stocking site.

into six statistical districts (Figure 1). Data were collected during 1979–1997 at fixed index locations in four areas: Nine Mile Point (MH-1), Rockport–Nordmeer–South Point (MH-2), Au Sable Point (MH-3), and Grindstone City (MH-4). These sites were designated for monitoring lake trout abundance and represent four of six statistical districts in western Lake Huron. Nine Mile Point was sampled every year during 1979–1997 except 1990. In MH-2, samples were taken at Rockport during 1979–1988, the *Nordmeer* wreck during 1989–1992, South Point during 1993–1994, and all three sites (Rockport, *Nordmeer* wreck, and South Point) during 1995–1997. The Au Sable Point and Grindstone City sites were sampled every year during 1979–1997.

Fish were collected by using graded-mesh, multifilament-nylon gill nets fished between late April and late June. Individual gill nets were hung on the half, 1.8 m deep, with mesh sizes ranging from 51 to 152 mm (stretch-measure) in 12.7-mm increments. A single box of gill nets contained nine 30.5-m panels, one panel of each mesh size, attached in ascending order of stretch measure. At all of the sites, multiple boxes were tied together and set in series as a gang. The nets were set on the bottom overnight across depth contours. For each sample, length of net, duration of set, location of the set, and date were recorded. For each lake trout captured, total length (nearest mm), weight (nearest 10 g), fin clips, sea lamprey wounds, sex, maturity, age, and stomach contents were recorded. All stocked lake trout had been marked either by removal of a year-class specific fin or by injection with a coded-wire tag (CWT) before they were stocked, so fish were aged based on year-specific fin clips or by CWT number. All lake trout stocked on Six Fathom Bank, an offshore reef (Figure 1), were injected with CWTs before stocking and were identified by CWT numbers.

Data analysis.—We used lake trout catch per effort (CPE) from spring assessment netting to index population density. The CPE of lake trout at age 5 was expressed as the number of age-5 lake trout per 305 m of net for each of the four districts. Lake trout identified as having been stocked on Six Fathom Bank were subtracted from the number in the catch. They were excluded from the calculation because stocking of these lake trout began in the last third of our time series (1985), relatively few fish from this isolated offshore reef contributed to the catch at the nearshore-sampling locations (Michigan Department of Natural Resources, unpublished data), and the extent of migration to nearshore areas has not yet been estimated. We calculated CPE by summing the catch of age-5 lake trout over all the sets at each district each year and dividing by the total effort at each district. For our analysis of all Michigan districts combined, we calculated CPE as the simple average of the four statistical district CPEs. Because all stocked lake trout are marked, the few unmarked fish were omitted from all CPE calculations.

We calculated adjusted CPE (our survival index) as CPE/(number stocked/500,000), where CPE was the age-5 CPE, number stocked was the number of yearling-equivalent lake trout stocked of that year-class, and 500,000 was the scaling factor. Fall fingerling lake trout were converted into yearling equivalents by multiplying the sum of all fingerlings stocked in an area by 0.4 (Elrod et al. 1988). For MH-1 and MH-2, we calculated each district's yearling equivalents as the sum of yearling-equivalent lake trout stocked at all sites within MH-1 and within MH-2, respectively, each year. Because the sampling locations in MH-3 and MH-4 were relatively close to each other and to the borders of the statistical districts, we calculated the number of yearling-equivalent lake trout stocked for MH-3 and MH-4 as the sum stocked in statistical districts MH-3, MH-4, MH-5, and MH-6 combined. This approach to handling stocking data is also in accord with what is known about how mortality components vary among areas in the lake. Sitar et al. (1997) found sea lamprey wounding patterns could best be explained by separating western Lake Huron into three areas: northern (MH-1), central (MH-2), and southern (MH-3, MH-4, and MH-5). Also, a large commercial gill net fishery operates in MH-1, whereas the fishery is limited in MH-2 and nonexistent in MH-3 and MH-4. For all Michigan districts combined, we calculated the number of yearling-equivalent lake trout stocked as the sum stocked in all Michigan statistical districts. Our analysis treated the numbers of fish stocked in each area as the number that would contribute to recruitment at age 5, if they survive.

Clearly, some fish move among these areas. Hence, we tested the robustness of our conclusions by performing an alternative analysis in which substantial movement (reallocation) among areas was assumed, and the results agreed qualitatively with the analysis we report. This lack of sensitivity to assumptions about movement stemmed from the fact that the relative number stocked in different regions did not change greatly over the year-classes used in our analysis.

In addition to examining plots of adjusted CPE over time, we also tested (at $P = 0.05$ level) for linear and exponential time trends by linear regression of adjusted CPE or $\log_e$(adjusted CPE) versus time for each statistical district and for all Michigan statistical districts combined. We found qualitatively similar patterns when testing for linear and exponential trends, but models fit better (less patterns in residuals) for the linear model, so we report only the tests for linear trends. We recognize that actual time trends will not follow exactly either a linear or exponential pattern; nonetheless, we use these tests as a way to objectively identify long-term patterns.

Results

In the Michigan waters of Lake Huron, adjusted CPE decreased for the 1974–1977 year-classes, increased for the 1978–1982 year-classes, decreased for the 1983–1986 year-classes, and increased for the 1987–1992 year-classes (Figure 2). Adjusted CPE showed different patterns over time for each statistical district. In MH-1, adjusted CPE decreased over time for the 1975–1982 year-classes and remained low for the 1983–1992 year-classes. In MH-2, adjusted CPE decreased for the 1974–1976 year-classes and remained low and variable for the 1977–1992 year-classes. In MH-3, adjusted CPE fluctuated without obvious pattern for the 1974–1985 year-classes and increased for the 1986–1992 year-classes. In MH-4, adjusted CPE decreased for the 1974–1976 year-classes, remained low for the 1977–1981 year-classes, and increased in variability for the 1982–1992 year-classes.

Adjusted CPE declined significantly in MH-1 ($t = -4.90$; df = 15; $P = 0.0002$). Trends were not significant for MH-2 ($t = -1.84$; df = 16; $P = 0.084$), MH-3 ($t = 1.23$; df = 17; $P = 0.235$), MH-4 ($t = 1.94$; df = 17; $P = 0.069$), or all Michigan statistical districts combined ($t = 0.30$; df = 17; $P = 0.766$).

Discussion

We interpret our results as showing that juvenile survival decreased over time in MH-1 but did not change significantly over time in MH-2, MH-3, or MH-4 or in all Michigan districts combined. The

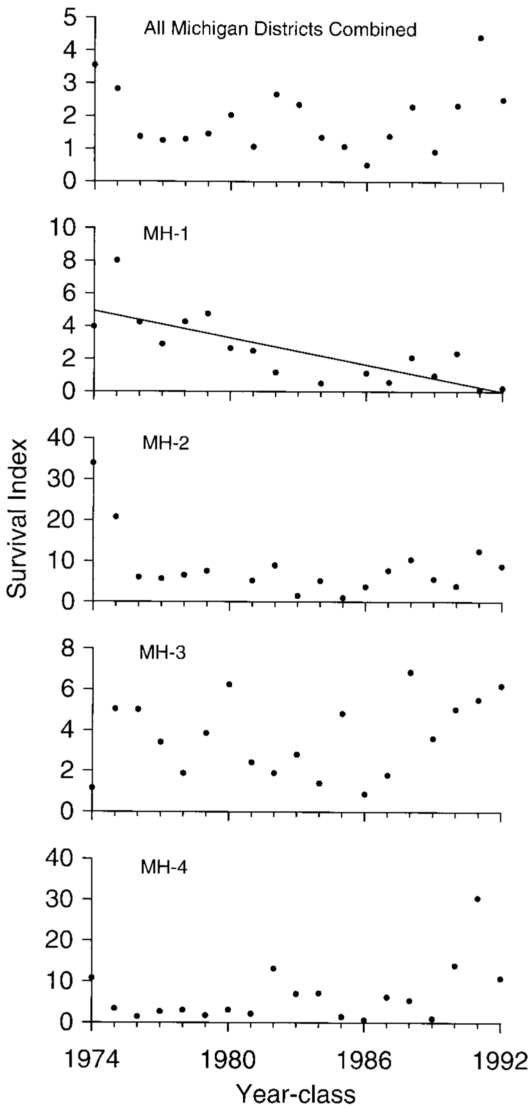

FIGURE 2.—Survival of juvenile stocked lake trout in all Michigan districts combined and in four separate statistical districts of Michigan waters of Lake Huron indexed by age-5 catch-per-effort divided by the number of each year-class stocked during 1974–1992.

trend in MH-1 was similar to those seen in Lake Ontario (Elrod et al. 1993) and Lake Superior (Hansen et al. 1996). Elrod et al. (1993) suggested that the decline in survival of stocked lake trout in Lake Ontario could be the result of predation by adult lake trout. Hansen et al. (1996) attributed the decline in survival of juvenile lake trout in Lake Superior to commercial gill-net fishing and predation by adult wild lake trout. In northwestern Lake Huron, predation by adult lake trout should not be increasing, because the abundance of adult lake trout in MH-1 followed the same decreasing trend as juvenile survival (Eshenroder et al. 1995), and no evidence of an increasing rate of cannibalism was seen (Michigan Department of Natural Resources, unpublished data). Gill-net fishing effort in MH-1 also did not show an increasing trend (Michigan Department of Natural Resources, unpublished data), so the decrease in juvenile survival was probably not the result of gill-net fishing mortality. In contrast, sea lamprey abundance in MH-1 increased since the early 1980s (Young et al. 1996), and increasing predation by sea lampreys is the most likely cause of decreasing juvenile survival. The St. Marys River, which flows into northwestern Lake Huron (Figure 1), is believed to be the spawning area primarily responsible for the increase in sea lamprey abundance (Young et al. 1996). Sea lampreys generally prefer large prey, if they are available (Swink 1991; Sitar et al. 1997). Northwestern Lake Huron has few large lake trout (Sitar et al. 1997), which provides little choice for sea lampreys. The mortality from a single sea lamprey attack for a 469–557-mm-long lake trout (age 4–6 in MH-1) is approximately 64% (Swink 1990). Because these juvenile lake trout represent the largest fish in the northwestern Lake Huron, they should be heavily selected by sea lamprey. In contrast, we think sea lamprey predation is less likely to affect juvenile lake trout survival in west-central and southwestern Lake Huron as in northwestern Lake Huron. Juvenile lake trout in west-central and southwestern Lake Huron are buffered from sea lamprey predation in these areas by the presence of larger adult lake trout, and sea lamprey abundance appears to be lower in these areas (Sitar et al. 1997). Thus sea lamprey–induced mortality is likely to be a less significant mortality factor in those areas for juvenile lake trout.

Although no significant trends appeared in MH-2, MH-3, MH-4, or all Michigan districts combined over the whole period, starting with the 1985 and 1986 year-classes the adjusted CPE appeared to be increasing in statistical districts MH-2, MH-3, and MH-4 (Figure 2). The increase in adjusted CPE in these districts and in all Michigan districts combined in 1985 and 1986 coincides with the use of the U.S. Fish and Wildlife Service research vessel *Togue* to stock fish offshore. Elrod (1997) showed that offshore stocking increased juvenile lake trout survival in Lake Ontario. Some lake trout have been stocked offshore in Lake Huron since 1972, and since 1985, lake trout have been released on the bottom, rather than at the surface, at offshore sites by using a pump and tube. Survival in Lake Huron appeared to increase starting with the 1985 and 1986 year-classes, the first year-classes stocked at offshore sites on the bottom. Release of fish on the bottom at offshore sites may have reduced the mortality from predation shortly after stocking. Nearshore predators, such as walleyes *Stizostedion vitreum* and double-crested cormorants *Phalacrocorax auritus*, should have relatively little effect on lake trout released offshore. Lake Huron also has few wild lake trout to prey on stocked lake trout, in contrast with some areas of Lake Superior (Hansen et al. 1996).

Our analysis showed that stock assessment methods assuming constant juvenile survival may not be appropriate for Lake Huron. In MH-1, the assumption of constant survival would not be valid, because the survival of juvenile lake trout decreased over time. However, this problem may not be as bad as thought at first glance, because most of the decrease occurred before 1984 and published assessments of lake trout stock use only data from 1984 to the present (Sitar et al. 1999). Also, the model of Sitar et al. (1999) explicitly accounts for sea lamprey–induced mortality. We believe the real problem with assuming constant juvenile survival lies in the amount of variability in survival over time. Adjusted CPE varied more than 30-fold in MH-2 and MH-4 and more than eightfold in MH-1 and MH-3 during 1974–1992. Because all of our time series of adjusted CPE were highly variable, and because time series of adjusted CPE for age-4 and age-6 lake trout showed relative year-class strengths similar to that for age-5 adjusted CPE (Michigan Department of Natural Resources, unpublished data), we believe that survival of juvenile lake trout in Lake Huron was also variable during 1974–1992. This variability in juvenile survival would cause less accurate estimation of parameters for models that assume constant juvenile survival, especially in MH-4, where most of the variability comes at the end of the time series. The problem is not as large for MH-1 and MH-2, because most of the variability in survival is at the beginning of the time series, before 1984. We advocate the use of stock assessment methods that incorporate variable juvenile survival to model Lake Huron lake trout populations. In part because of our results, the Technical Fisheries Committee, charged with lake trout assessments in waters ceded under the 1836 Treaty of Washington in lakes Huron, Michigan, and Superior, has adopted such methods.

Because the mortality of juvenile lake trout did not increase significantly in most of western Lake Huron, apparently stocking hatchery-reared lake trout is still a viable management option for building and maintaining an adult lake trout stock in Lake Huron, a necessary condition for lake trout rehabilitation. However, even with apparent increases in survival since the 1985 year-class, survival by the end of the time series was not greater than during the beginning of the time series, except in MH-4.

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