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GROWTH, MORTALITY, RECRUITMENT, AND MANAGEMENT OF LAKE TROUT IN EASTERN LAKE MICHIGAN[1]

Ronald W. Rybicki

[1]A contribution from Dingell-Johnson Project F-53-R, Michigan.

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Growth, Mortality, Recruitment, and Management of Lake Trout in Eastern Lake Michigan

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Abstract.—In 1985, the State of Michigan and the Indian tribes of Sault Ste. Marie, Bay Mills, and Grand Traverse entered a court-sanctioned agreement which mandated the setting of catch quotas for lake trout in the treaty waters of northern and eastern Lake Michigan. The objectives of this report are: (1) to describe growth, recruitment, mortality, and management of lake trout stocks in eastern Lake Michigan from 1984-88, and (2) to provide the catch quotas set annually during 1984-89.

Analysis of growth rate-at-age of the 1970-84 year classes showed no statistically significant trends. Growth rates were highly variable but neither declined nor increased for more than three successive years.

Since 1975, annual total mortality rates of lake trout stocks recruited to the fisheries have ranged from 46%-77%. In the primary rehabilitation zone, annual total mortality rates ranged from 69% in 1984-85 to 77% in 1988-89.

Reproductive failure may be have been due to insufficient numbers of spawning lake trout caused by the excessive mortality rates. Spawning frequency averaged 0.2 times/stocked female lake trout in the primary rehabilitation area during 1985-88. If recommended catch quotas were adhered to in the primary rehabilitation zone, then in 15 years the spawning frequency would increase to 1.5 times/stocked female lake trout, and potential egg production would increase from the 1985-88 average of 8 million to 89 million.

During 1984-89, annual harvest quotas in all zones ranged from 6.9-29.1 thousand lake trout. However, annual fishing rates exceeded the target fishing rate by 2.8-5.3 times during 1984-88.

Lake Michigan's lake trout resource can be fairly characterized as plant, grow, and harvest, because management efforts have failed to control exploitation of the species. Either more effective regulations need to be devised and enforced, or the goal of reconstructing the lake trout population in eastern Lake Michigan should be abandoned. A forthrightly stated policy should be formulated jointly by the Michigan Department of Natural Resources and the Indian tribes which sets the direction that management of lake trout stocks is to take in eastern Lake Michigan.

In 1985, the State of Michigan and the Indian tribes of Sault Ste. Marie, Bay Mills, and Grand Traverse entered a court-sanctioned agreement to resolve the dispute overfishing rights in the upper Great Lakes exercised under the Treaty of 1836. Part of the agreement mandated that lake trout (*Salvelinus namaycush*) in the treaty waters of northern and eastern Lake Michigan be managed by catch quotas.

Reconstruction of the overexploited, lamprey-decimated lake trout population in Lake Michigan began in 1965. Since that time, the lake trout population has been sustained almost entirely through annual stocking of hatchery-reared lake trout. Consequently, the intent of controlling harvest through quotas was to build spawner biomass and thereby increase reproductive potential by the lake trout population.

For the purpose of lake trout management, the state/tribal agreement divided the treaty waters of Lake Michigan into four regions (Figure 1):

Primary region.—Restoration of lake trout stocks is the primary management objective. However, the harvest of lake trout is permissible within an established quota.

Secondary region.—Restoration of lake trout stocks is of secondary management priority. The harvest of lake trout is permissible within an established quota.

Deferred region.—Not managed for lake trout. Lake trout which stray into the deferred zone may be treated as a commercial species without restrictions on quantity harvested. However, a minimum size limit and seasonal restrictions are in effect.

Northern refuge.—An area reserved to build spawner biomass of lake trout to maximize the opportunity for natural propagation by the species. The harvesting of lake trout by any means is prohibited.

Despite court directives and a long-standing commitment to rehabilitation of the lake trout population in Lake Michigan, neither state nor tribal management authorities have enforced the harvest quotas set for lake trout. Indeed, the lake trout stock in the primary rehabilitation region has been subjected to higher mortality rates because of sport and commercial fishing than the lake trout stocks in the secondary rehabilitation region.

The objectives of this report are to 1) describe the growth, mortality, recruitment, and management of lake trout stocks in eastern Lake Michigan from 1984-88 and 2) provide the catch quotas set annually during 1984-89.

Methods

Sampling

Graded-mesh gill nets were used in the study to capture lake trout. Eight mesh sizes, which ranged from 64-152 mm (stretch measure) on an interval of 13 mm, were used. A subgang consisted of eight panels, each of which was 30.5 m long x 1.8 m deep, and the eight mesh sizes were sequentially ordered from smallest to largest. A gang consisted of three subgangs tied together for a total length of 731.5 m.

These gill nets were fished annually at 11 index stations from early April through mid-June during 1984-89 (Figure 2). A sample quota of 200 lake trout was set at each index station. However, if the sample quota could not be caught within 48 hours, fishing activity was suspended at that station.

The sampling area was divided into three units which were designated as the northern, central, and southern zones (Figure 2). The zones were large enough to minimize the analytical problem caused by lake trout stocks migrating into or out of the area.

Analyses

The Robson-Chapman (1961) model for catch-curve analysis was used to estimate annual survival rates. To minimize violation of the model's requirement of constant recruitment, index catches of lake trout were standardized per 100,000 planted in each year class. After standardizing for planting density, the number-at-age was proportionately adjusted so that the sum of standardized data equaled the total number in the sample. This step was necessary because an artificially large or small sample size influenced the variance on the survival estimate, which in turn affected the model's decision to include or exclude the youngest age group in the catch-curve analysis.

Analyses of growth (instantaneous rate of increase in length) were based on data pooled into 5-year periods of 1970-74, 1975-79, and 1980-84 because mean growth rates among year classes did not differ significantly when grouped into 5-year intervals within zones (Table 1; Appendices A1-A3). Samples of less than five fish or older than age 8 were excluded from the analyses.

Clark and Smith's (1985) *Stock Assessment Program* was used to estimate the age distribution and egg production at several levels of minimum size limits (MSL) and fishing rates. The growth parameters and maturity data required by Clark and Smith's model are given in Appendices B1 and B2. The number of eggs per lake trout used to generate egg production estimates was 1,128 per kg of female (D. Galvin, Michigan Department of Natural Resources, personal communication).

Standing stocks were estimated by multiplying the number of trout planted as yearlings, or yearling equivalents when planted as fall fingerlings, by survival rate at successive ages (Appendix C). Year classes planted as fall fingerlings were converted to numbers of yearling equivalents using fall to spring survival rates provided by R. Hatch (U. S. Fish and Wildlife Service, personal communication; Table 2). Survival rates used for 1 and 2 year olds were those reported by Rybicki (1990) for hatchery-reared lake trout planted in Grand Traverse Bay of Lake Michigan. Annual natural mortality rate of pre-recruits older than 2 years was assumed to be 25% ($M=0.288$) as estimated by Rybicki and Keller (1978) for lake trout 5 years old and older. The mean age of lake trout recruited to the sport fishery was determined from sport-caught lake trout. Size-and-age data at which lake trout were recruited to the commercial fishery were not available.

Since all planted lake trout are fin clipped, the proportion of unmarked fish in the index samples were used as an indicator of natural reproduction after adjustment for fin clipping error and regeneration of excised fins. From 1975 to 1980, the mean frequency of unclipped trout was 0.5% (±1.5%) in the catch at five index stations from Little Traverse Bay to Pentwater (Rybicki 1983). The estimates of the proportional magnitude of natural reproduction were made by using the upper confidence limit of the mean percentage (0.5% + 1.5% = 2.0%) to compute the expected frequency of unclipped trout, and comparing it to the observed frequency of unmarked trout.

Harvest quotas (in number) were based on the standing stock at the mean age of recruitment to the sport fishery through age 14+ and a target exploitation rate of 17.5% annually.

Results

Growth Rate

No long-term trends were observed in the growth rate of lake trout during 1970-84 in the central and northern zones. Instantaneous growth rate-at-age of lake trout showed no statistically significant differences among year classes in either slope or elevation of regression lines within a zone (Table 3). Since consistent indexing of lake trout in the southern zone did not begin until 1986, the number of data points was insufficient to examine growth patterns of lake trout in that region. Within an age group and zone, growth rates fluctuated considerably from one year to the next, but they varied without statistical trend ($P > 0.05$; Figure 3). In the central zone, the temporal patterns of lake trout growth rates among age groups 4-8 were strikingly similar (Figure 3). Growth patterns among age groups of lake trout from the northern zone were not correlated. Too many data points were missing in the 7- and 8-year-old groups to compare growth trends.

Mortality Rates

Trend lines of total mortality rates in the fishable segment of the lake trout populations in the northern and central zones have been upward each year from 1975 to 1988 (Figure 4). In the southern zone, the trend-line mortality rates have increased steadily since 1979. Given a constant, instantaneous rate of natural mortality of 0.288 (Rybicki and Keller 1978), the predicted rates of exploitation ranged from a low of 22% in the northern zone in 1976 to 61% also in the northern zone in 1988 (Table 4).

Natural Reproduction

Little evidence of successful reproduction by lake trout, as determined from unclipped fish in the index catch, has been found in eastern Lake Michigan. Some unclipped lake trout are occasionally found. However, the percentage of unclipped trout as the result of not having been marked in the hatchery appears to be minor. Of 4,581 yearling lake trout examined shortly after stocking in Grand Traverse Bay, only three were unclipped. Regeneration of excised fins with increased age also has been suggested as an explanation for the sometimes greater frequency of unmarked, older fish. Although regeneration of clipped fins certainly has occurred, it is often detectable because of the fin being shorter or of irregular shape. Moreover, there was no statistically significant correlation ($R^2 = 0.01$; $P = 0.75$) between age and the proportion of unmarked lake trout in the index catch from Grand Traverse Bay during 1983-89.

The 1976 and 1981 year classes in Grand Traverse Bay and the 1983 cohort in Platte Bay contained significantly larger frequencies of unmarked lake trout than would be expected because of marking and regeneration error (Table 5). When the clip error rate of 2% is subtracted from the observed clip rate, about 13% of the 1976 year class and 7% of the 1981 are attributed to natural recruitment in Grand Traverse Bay, and 4% of the 1983 year class in Platte Bay is considered to be of feral origin.

The virtual reproductive failure of lake trout in Lake Michigan may be caused by an inadequate number of spawners. If catch quotas were adhered to in the northern, primary rehabilitation zone, I estimate that in 15 years the lowered mortality rate would increase lake trout 6 years of age and older in the population from 6.3% to 25.7%, the average number of spawnings per female would increase from 0.2 to a 1.5 (Table 6), and potential egg production would rise from 8.1 million to a maximum of 89.0 million (Table 7). Various minimum size limits (MSLs) at the mean fishing rate (F = 1.051) extent in the northern zone during 1985-88 indicated that the percentage of trout 6 years old and older would rise from 6.3% at 537 mm to 30.8% at 711 mm, and it would require only 9 years to do so. Spawning frequency would increase dramatically from 0.2 to 4.4 times per stocked female, and egg production would increase from 8.1 million to 95.3 million.

Minimum size limits appeared to be relatively less effective when the target fishing rate was 0.223 (A = 40%) than at the observed mean F of 1.051. In the northern zone, the percentage of 6 year and older fish edges upward from 26% at 537 mm to 37% at 711 mm, mean spawning frequency increases from 1.5 to 5.9, and egg production rises from 89 million to 168 million. The years to equilibrium at the target fishing rate are about twice that for the mean fishing rate, which may give the impression that the combination of high fishing rate and MSL is preferable to the target fishing rate and MSL. However, in the northern zone, when age composition of the population, spawning frequency per female, and egg production are estimated at the same number of years required to attain equilibrium at the mean fishing rate, these parameters are much greater at the target fishing rate than at the mean fishing rate at any given MSL (Table 8).

The level of egg production required to rehabilitate the population is unknown. A simulation exercise by Clark and Huang (1985) suggested that, when first-year survival was as low as 0.005, only complete closure of the lake trout fisheries would allow the stock to attain a rehabilitation goal of 25 thousand wild, 4-year-old fish in the northern sector of the central zone. Their work also indicated that rehabilitation of the lake trout stock could be achieved in less than 25 years provided that the first-year survival were as large as 0.01, stocking rates were maintained, and a minimum size limit of 711 mm were imposed on the fisheries. Under these conditions, they estimated that egg production would be 42.8 million within their study area, which implies egg deposition per unit area. In the absence of areal quantification of spawning habitat, egg production was standardized to deposition per 113 km of shoreline within each zone to correspond to the egg production of 43 million per 113 km of shoreline in Clark's and Huang's study (1985). Under the mean stocking and total mortality rates extent in 1985-88, an MSL of 686 mm in the northern zone would have allowed a production of 43 million eggs per 113 km of shoreline in about 5 years (Table 9a); at the target *F* and an MSL of 537 mm, the goal could also be reached in 5 years. However, a target production of 43 million eggs per 113 km of shoreline would not have been attainable under the mean stocking and fishing rates at any MSL in either the central or southern zones (Tables 9b, 9c). A part of the reason is that only about one-half as many lake trout were planted in these two regions as were stocked in the northern zone. In the central zone, a production of 43 million eggs per 113 km of shoreline appears possible at the target fishing rate of 0.223 and an MSL of 711 mm in 7 years. In the southern zone, at the target fishing rate the number of years required to attain the target production of 43 million eggs is inversely related to the MSL. At an MSL of 635 mm the target production is approached in 10 years, in 5-6 years at 660 mm, in 4 years at 686 mm, and 3-4 years at 711 mm (Table 9c).

Harvest Quotas

Harvest quotas (numbers) of lake trout ranged from a high of 29.2 thousand in the northern zone in 1988 to a low of 6.9 thousand in the central zone in 1988 (Table 10). For all years and zones, the fishing rate on lake trout by the sport and commercial fisheries exceeded the target fishing rate (0.223) by 2.8-5.3 times. In the northern zone, the Indian gill-net fishery accounted for 65%-75% of the harvest during 1985-88 (Table 11).

Numbers of lake trout planted offshore in the northern refuge were excluded in the estimated standing stock along the eastern shoreline (inshore) of the northern zone. Inclusion of the refuge stock would have caused the harvest quota to be disproportionately large, which would have intensified an already unacceptably large fishing rate on the northern zone population.

Discussion

In recent years, concern has been expressed over ability of the forage base to support indefinitely the present growth rates of large numbers of salmonines being stocked in Lake Michigan. In the early 1980s, an apparent, lakewide decrease in the average size of sport-harvested salmon and trout was theoretically linked to significant perturbations in the species composition of the forage base. Alewives (*Alosa pseudoharengus*), which are an important staple in the diet of lake trout and salmon (Kogge 1985), have declined in abundance from 80% of the forage biomass in the mid 1960s (Smith 1968) to about 14% in 1987 (Keller and Smith 1990). As a result, the Michigan Department of Natural Resources (MDNR) decided to reduce stocking rates of chinook salmon in Lake Michigan by 10% during 1985-90 (Westers et al. 1990). However, my data indicated that the shift in species composition of the forage base from alewives to bloater chubs (*Coregonus hoyi*) has had no profound impact on the growth rate of lake trout in eastern Lake Michigan. Analyses of growth rates-at-age of lake trout showed no statistically significant trends during 1970-84. Because of the instability of growth rates of lake trout, a decline in the rates over several years does not necessarily portend disaster. The growth curves clearly show that no decrease in growth rate occurred for more than three successive years. Eck and Brown (1985) estimated that the biomass of lake trout could be increased by 15-21 thousand tonnes in the whole of Lake Michigan. Given the lack of trends in growth rates, large variation in annual growth rates, and the results from Eck's and Brown's (1985) modeling exercise, reduced stocking rates of lake trout may not be necessary to maintain present growth rates of the species.

Despite court directives and a long-standing commitment to rehabilitation of the lake trout population in Lake Michigan, neither state nor tribal management authorities have enforced the harvest quotas set for lake trout. The unacceptably large mortality rates of lake trout in the southern and central zones, which are of secondary rehabilitation priority, were induced by the sport fishery. In the northern zone, where lake trout restoration ostensibly is top priority, about two-thirds of the exceptionally high mortality rates were attributed to the Indian gill-net fishery.

A severe shortage of spawning lake trout in Lake Michigan and the resultant low egg deposition may be the primary cause of reproductive failure. Dorr et al. (1981) suggested that the number of lake trout eggs deposited on spawning grounds in south-eastern Lake Michigan appeared to be critically low when compared with egg densities on spawning grounds in self-sustaining lake trout populations in other lakes. I believe the cause of low spawner density has been high total mortality rates, which ranged from 46%-76% during 1975-88, of 4 year old and older lake trout in Lake Michigan. Healey (1978) concluded that self-sustaining populations of lake trout with natural mortality rates in the range of 20-30% could withstand fishing until annual total mortality reached 50%. When the total mortality exceeded 50%, the lake trout populations were in serious difficulty. Pycha (1980) also suggested that a total mortality rate of 50% or more may preclude restoration of spawning stocks of lake trout in Lake Superior. Also, planted lake trout may have a lower spawning efficiency than do naturally produced trout. Thus, even a 50% total mortality rate may not allow escapement adequate to generate reproduction. The natural mortality rate of Lake Michigan's lake trout vulnerable to fishing falls within the range given by Healey (1978), and in most years annual total mortality rates exceeded 50%. These findings were the bases for the Lake Michigan Lake Trout Technical Committee's recommendation of a target total mortality of 40% annually on the exploitable segment of the lake trout population (Brown 1983).

In the northern zone, where rehabilitation of lake trout is the highest priority, total mortality rates have been well in excess of 40% since 1976 and averaged 65% during 1985-88. From 1985-88, the average number of spawnings per female lake trout caught by the sport fishery was 0.2, which means that only one out of every five female lake trout had an opportunity to spawn once before being caught. If given protection through the adherence to harvest quotas (based on F = 0.223 and MSL = 537 mm), the average number of spawnings per female lake trout in the northern primary zone potentially would increase from 0.2 to 1.5, and egg production would rise from 4.9 million/113 km of shoreline to a maximum of 54.2 million/113 km of shoreline in 15 years. Fifteen years are required for maximum egg production because equilibrium is reached asymptotically. To achieve a target production of 43 million eggs per 113 km of northern zone shoreline would require only 5 years.

Despite the adversities, a small amount of natural recruitment was found in Grand Traverse Bay. On the average, a detectable level of natural recruitment occurred in only one of every five year classes of lake trout in Grand Traverse Bay. Although encouraging, the estimated natural recruitment was only a modest proportion of a cohort, occurred infrequently, and was not geographically widespread.

The MDNR has made efforts to reduce the fishing mortality of lake trout. In the late 1960s, it became clear that lake trout restoration could not be achieved in the presence of the commercial gill-net fishery for whitefish. Conversion of the gill-net fishery to trap nets in the late 1960s-early 1970s paved the way for reconstruction of lake trout populations and the successful introduction of Pacific salmon. Regulation of the sport fishery, a major source of lake trout mortality, was tightened by a reduction in creel limit from five lake trout/angler/day prior to 1979 to three and then to two in 1982.

Additionally, the angling season was shortened in 1984 from year-round to May 1 through August 15, although in 1989 the season was extended through Labor Day.

Nevertheless, since the conversion of the commercial gill-net fishery to trap nets in the early 1970s, meaningful efforts to restore self-perpetuating populations of lake trout have failed. A major reason is that both sport and commercial harvest of lake trout have intensified despite attempts to lower them through regulations. Reduced creel limits and a shortened season have neither decreased nor stabilized the total mortality rates of lake trout. In the northern rehabilitation zone, the state-licensed trap-net fishery was displaced in 1985 by an Indian gill-net fishery that has been incompatible with lake trout restoration. Harvest quotas for lake trout, which have been set annually since 1979, have not been enforced by state or tribal management authorities. Consequently, fishing rates on lake trout by the sport and commercial fisheries exceeded the target rate by 2.8-5.3 times during 1984-88. Clearly, the setting of harvest quotas is a non-functional, institutionalized ritual performed yearly with no positive impact on the lake trout resource in Lake Michigan.

Because managers have not dealt effectively with the unacceptably high mortality rates, which I believe have had a devastating impact on the numbers of spawners, management of Lake Michigan's lake trout resource can be fairly characterized (or criticized, depending on one's point of view) as plant, grow, and harvest. It is now time to reassess the commitment to rehabilitation of lake trout in eastern Lake Michigan in light of the present situation. Either more effective regulations need to be devised and enforced, or the goal of reconstructing the lake trout population should be officially abandoned. A forthrightly stated policy should be formulated jointly by the MDNR and the tribes which set the direction that management of lake trout stocks is to take in eastern Lake Michigan.

If reconstruction of a feral lake trout population in Lake Michigan is a goal to be pursued seriously, Keller and Smith (1990) persuasively argued that rehabilitation strategies must allow for the realities of the present: Lake Michigan now has a community of fishes significantly altered from pre-lamprey days when lake trout were the only salmonine predator; tough regulations must be imposed to decrease fishing-induced mortality; the multimillion dollar sport fishery developed on planted stocks is real and here to stay; most sportfishing interests feel that lake trout should be managed for a put, grow, and harvest fishery as are salmon; and stability of a high quality sport fishery can only be sustained through a multispecies mix of trout and salmon. The last proposition not only acknowledges that lake trout are an important part of the species mix, but also implies that wild lake trout stocks should not be established at the expense of popular sport fisheries for salmon and hatchery-reared trout.

Under a management scheme of plant, grow, and harvest, the main biological consideration is that lake trout be harvested at a size which maximizes yield. In a self-sustaining population, harvest ideally would be restricted to the biomass that is surplus to the maintenance of the fish population. However, in the case of Lake Michigan, all lake trout are surplus, because stocks are sustained artificially by annual infusions of hatchery fish. The size at which biomass of fish is maximized is the critical size. Critical size is the average weight of fish in a year class when the instantaneous rate of natural mortality equals the instantaneous rate of growth (Ricker 1975). The average critical size of lake trout in Lake Michigan is about 1.9 kg and 582 mm. Clearly, the annual harvest of lake trout cannot occur instantaneously at exactly 582 mm. However, under recent past conditions, the harvest-at-size of lake trout by the sport fishery brackets the critical size, and may be as close to harvesting at the critical size as can be achieved. From 1985 through 1988, 53% of the lake trout creeled from Lake Michigan were in the 533-635 mm length classes, and the mean total length was 625 mm (G. Rakoczy, MDNR, personal communication).

Recommendations

1. That a management policy and goals be formulated jointly by the MDNR and the tribes which forthrightly state the direction that management of lake trout stocks is to take in eastern Lake Michigan, and that the policy and goals be assiduously pursued.

2. When a management policy for lake trout has been defined, design strategies to implement that policy.

Acknowledgments

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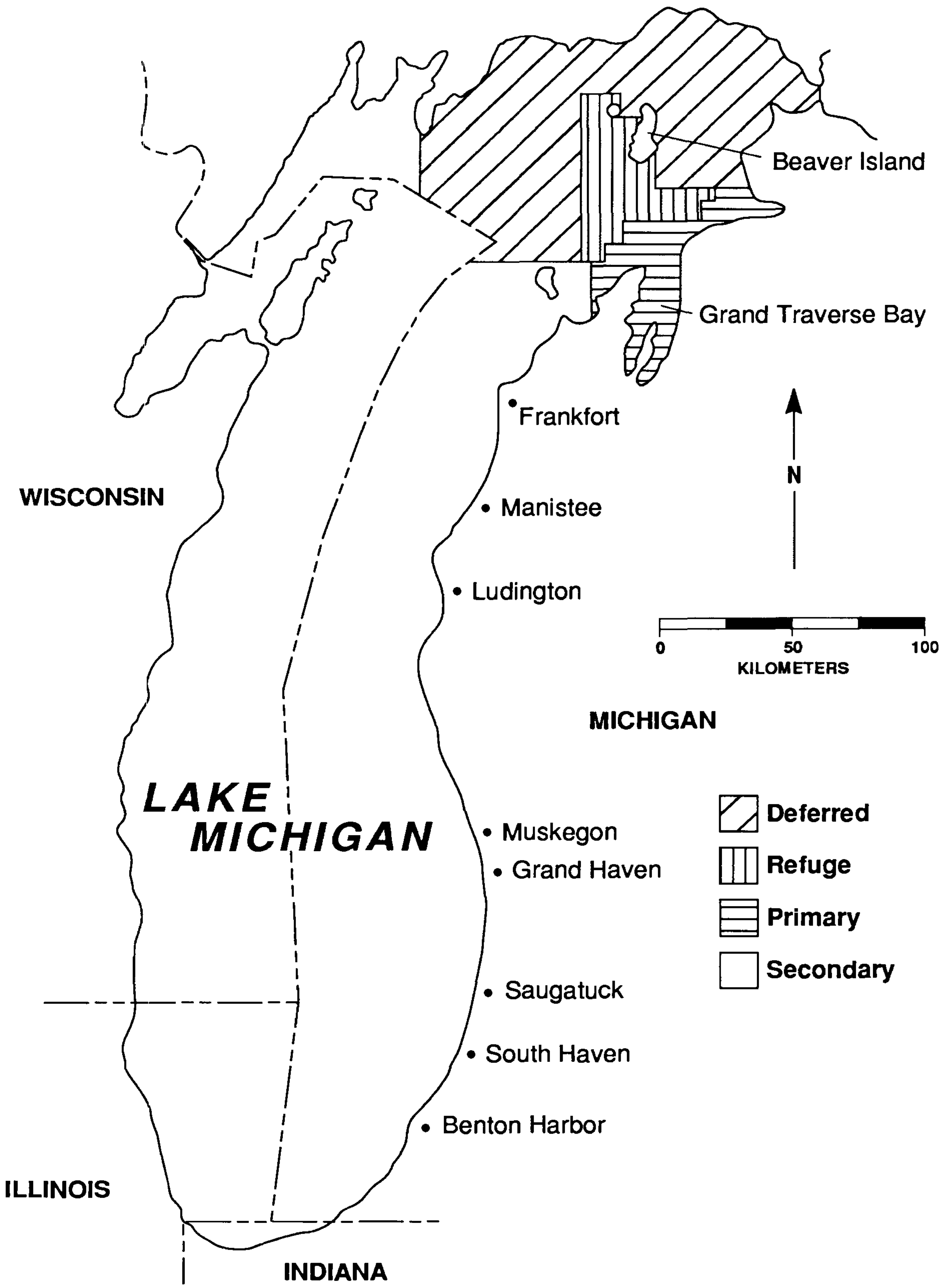

Figure 1.—Deferred, primary, secondary, and refuge regions for lake trout management in Lake Michigan.

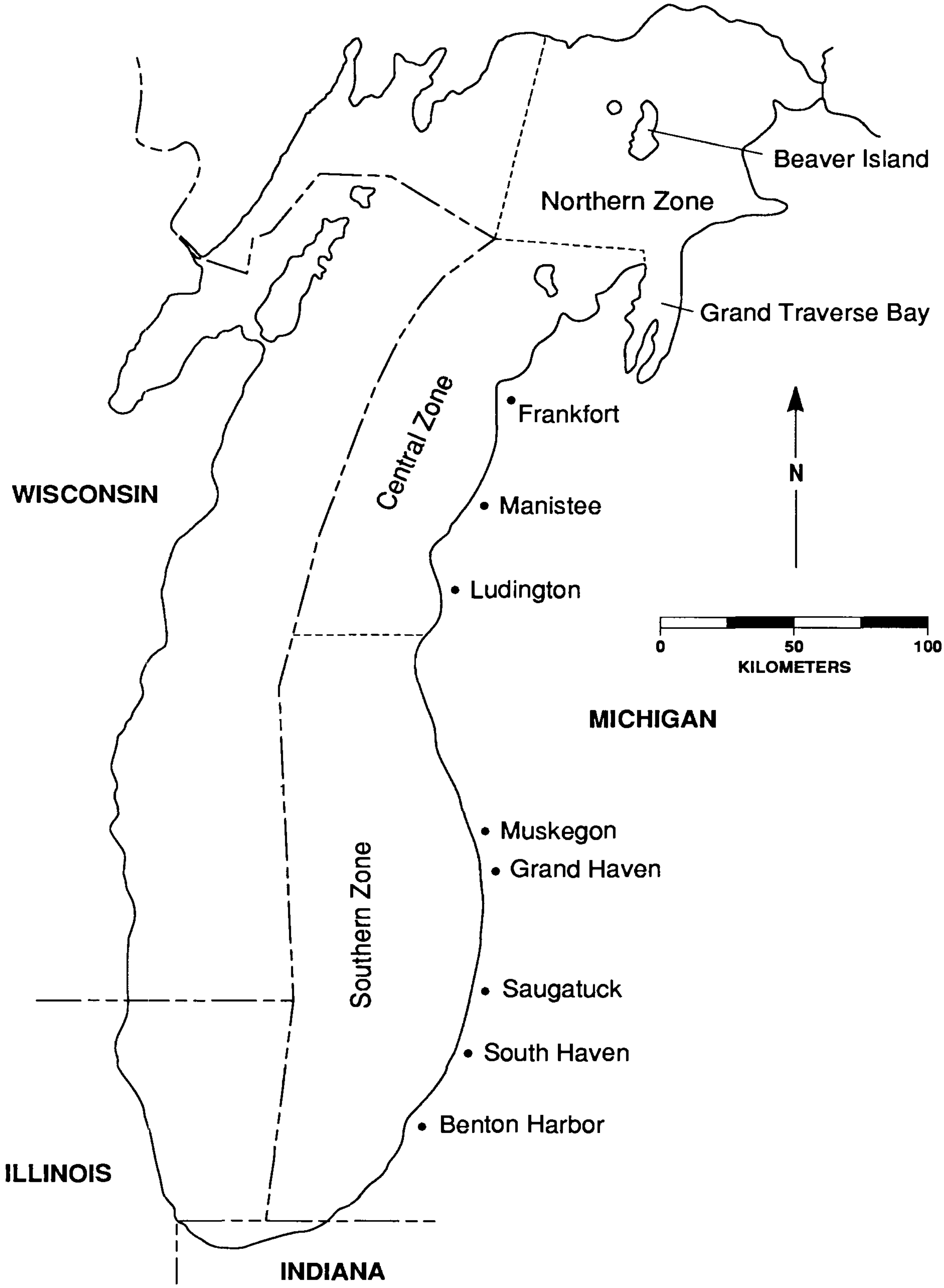

Figure 2.—Lake trout zones on Lake Michigan.

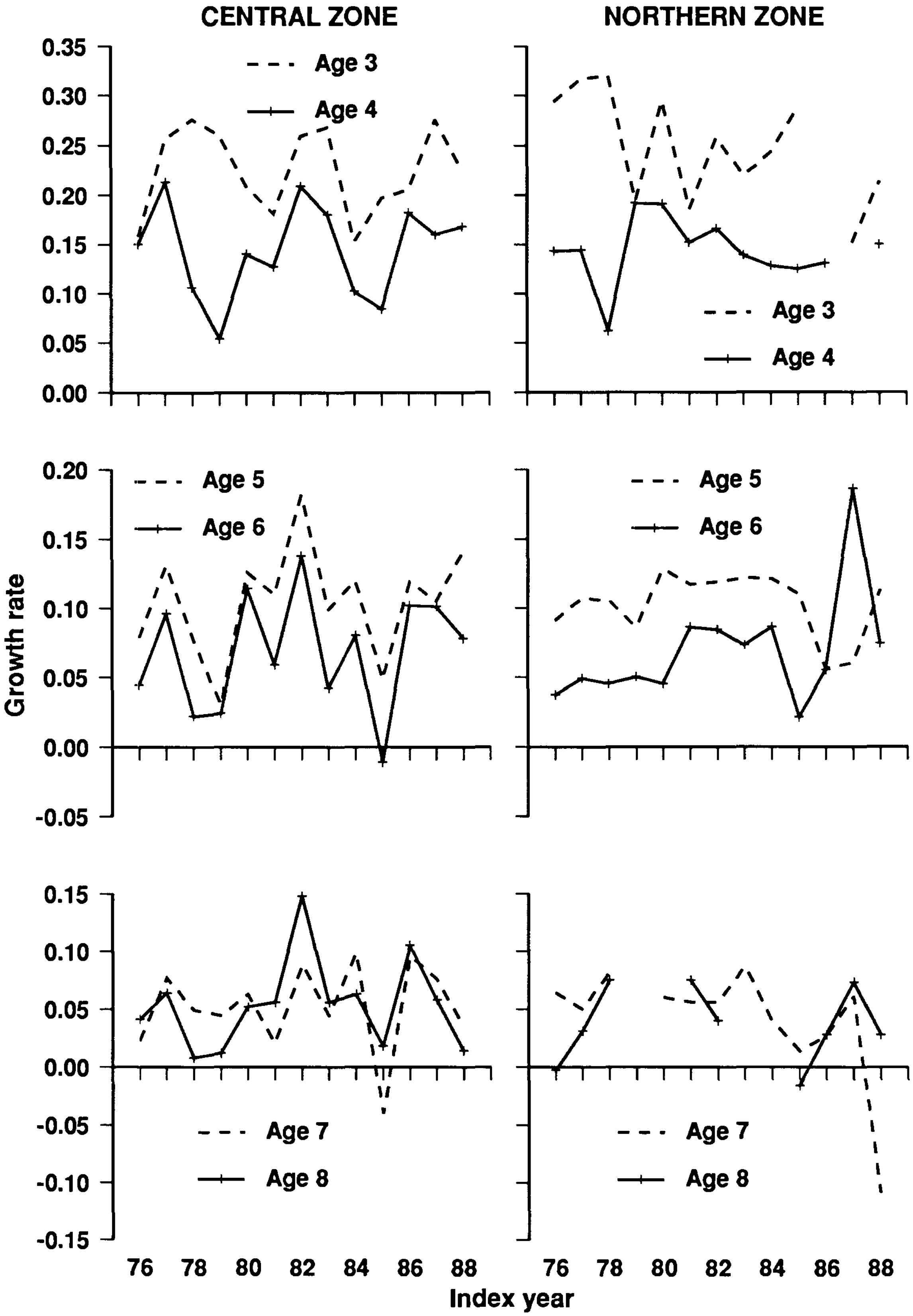

Figure 3.—Trends of instantaneous growth rates of Lake Michigan lake trout, by zone and age group.

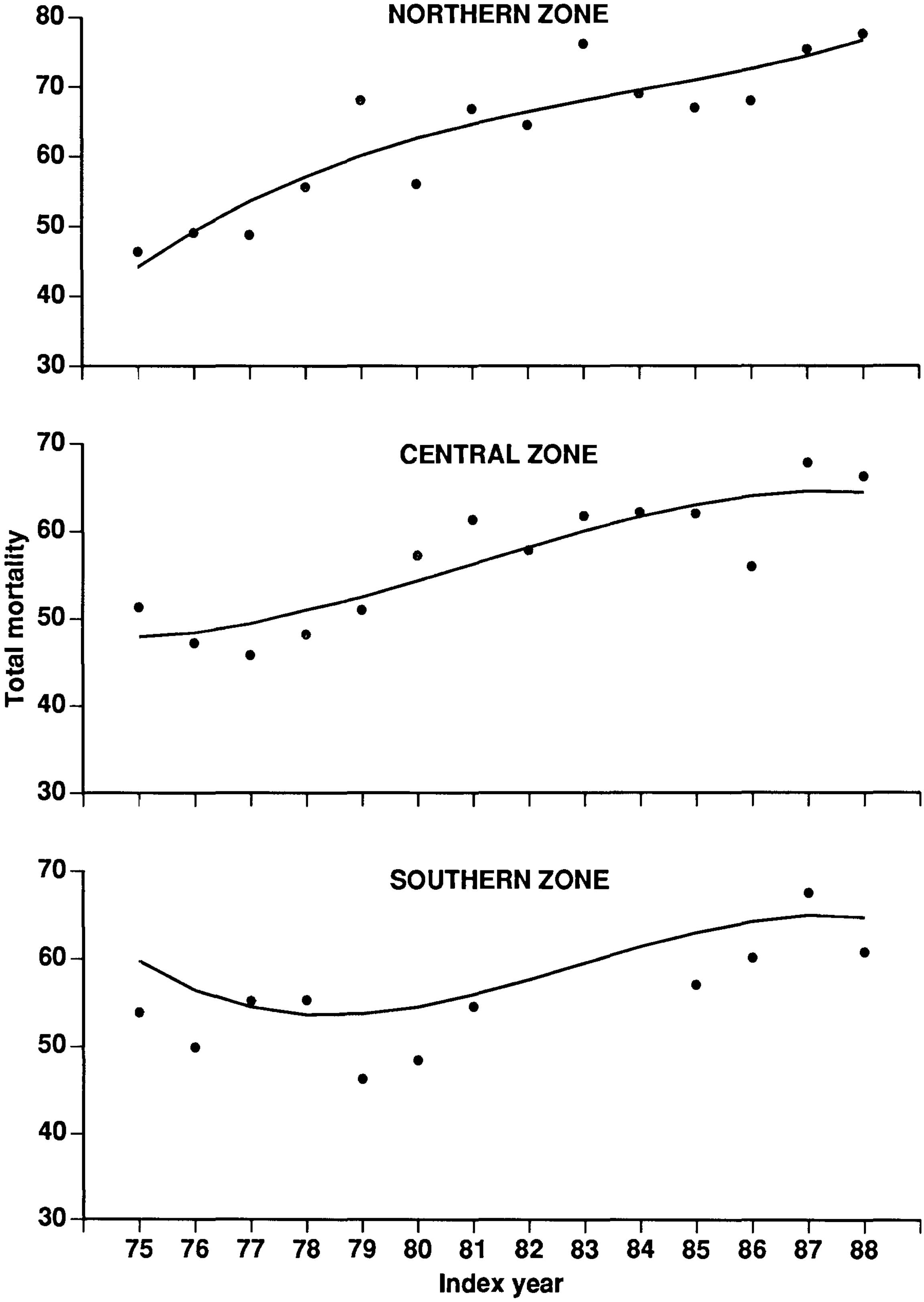

Figure 4.—Predicted annual total mortality rates (percent) of lake trout recruited to the fishery, in Lake Michigan , by zone.

Table 1.—Comparisons of instantaneous growth rates (total length in mm) of year classes of lake trout, by zone. Trout older than 8 years or sample sizes of less than five fish were excluded from the analysis.

Zone	Year class	Mean growth rate	One-way ANOVA Source	Degrees freedom	Sum of squares	Mean squares	*F* ratio	Probability of *F*
Northern	1970	0.0540	Between	4	0.0144	0.0036	0.5857	0.677
	1971	0.0643	groups					
	1972	0.0983						
	1973	0.1213	Within	17	0.1042	0.0061		
	1974	0.1100	groups					
	All	0.0955						
	1975	0.1815	Between	4	0.0200	0.0050	0.6655	0.623
	1976	0.1346	groups					
	1977	0.1105						
	1978	0.1003	Within	22	0.1653	0.0075		
	1979	0.1065	groups					
	All	0.1223						
	1980	0.1003	Between	4	0.0071	0.0018	0.1773	0.946
	1981	0.1004	groups					
	1982	0.1382						
	1983	0.1130	Within	13	0.1304	0.0100		
	1984	0.1510	groups					
	All	0.1151						
Central	1970	0.0430	Between	4	0.0137	0.0034	0.7899	0.546
	1971	0.0590	groups					
	1972	0.0798						
	1973	0.0985	Within	19	0.0824	0.0043		
	1974	0.1123	groups					
	All	0.0845						
	1975	0.1100	Between	4	0.0010	0.0003	0.0402	0.997
	1976	0.0990	groups					
	1977	0.1128						
	1978	0.1057	Within	24	0.1557	0.0065		
	1979	0.1170	groups					
	All	0.1092						
	1980	0.1017	Between	4	0.0317	0.0079	1.8397	0.174
	1981	0.0984	groups					
	1982	0.1405						
	1983	0.1690	Within	15	0.0647	0.0043		
	1984	0.2220	groups					
	All	0.1307						

Table 2.—Survival schedule used to estimate the standing stock of lake trout in Lake Michigan.

Age	Number per kg	Annual survival[1]
Fall fingerlings	>77	0.20
	55-77	0.30
	<55	0.40
1 (yearlings)		0.40
2		0.59
3		0.75
4 to 4.x		$e^{-0.288(4.x-4.0)}$
4.x to 5		$e^{-Z(5.0-4.x)}$
≥5		Observed

[1]x is the mean fractional age at recruitment to the sport fishery; Z is the observed instantaneous total mortality rate at age 5.

Table 3.—Estimated length-at-age parameters of lake trout in the central and northern zones of Lake Michigan.

Statistical zone	Grouped year classes[1]	Regression parameters[2]	
		Intercept (a)	Slope (b)
Central	1970-74	0.3560	-0.1555
	1975-79	0.4035	-0.1761
	1980-84	0.4187	-0.1906
	All	0.3940	-0.1736
	Probability[3]	0.620	0.660
Northern	1970-74	0.3949	-0.1760
	1975-79	0.4531	-0.1929
	1980-84	0.4287	-0.1977
	All	0.4223	-0.1902
	Probability[3]	0.340	0.810

[1]Includes age groups 3-8.

[2]$Y_{mm} = a + b(\ln X_{age})$.

[3]Probability that intercepts and slopes differ among grouped year classes.

Table 4.—Estimated and predicted mortality rates of exploitable lake trout in Lake Michigan, by zone and year.

				Predicted mortality rates		
		Estimated	Annual	Instantaneous		Annual
		annual	total	Total	Fishing	exploitation
Zone	Year	total	(A)	(Z)	(F)	(U)
Northern	1975-76	0.464	0.442	0.583	0.295	0.224
	1976-77	0.491	0.493	0.679	0.391	0.284
	1977-78	0.488	0.536	0.768	0.480	0.335
	1978-79	0.556	0.571	0.846	0.558	0.377
	1979-80	0.681	0.601	0.919	0.631	0.413
	1980-81	0.560	0.626	0.983	0.695	0.443
	1981-82	0.669	0.646	1.038	0.750	0.467
	1982-83	0.645	0.664	1.091	0.803	0.489
	1983-84	0.762	0.680	1.139	0.851	0.508
	1984-85	0.690	0.695	1.187	0.899	0.526
	1985-86	0.670	0.710	1.238	0.950	0.545
	1986-87	0.680	0.726	1.295	1.007	0.564
	1987-88	0.775	0.745	1.366	1.078	0.588
	1988-89	0.777	0.768	1.461	1.173	0.617
Central	1975-76	0.513	0.479	0.652	0.364	0.267
	1976-77	0.472	0.484	0.662	0.374	0.273
	1977-78	0.458	0.494	0.681	0.393	0.285
	1978-79	0.482	0.51	0.709	0.421	0.302
	1979-80	0.510	0.524	0.742	0.454	0.321
	1980-81	0.572	0.543	0.783	0.495	0.343
	1981-82	0.613	0.562	0.826	0.538	0.366
	1982-83	0.578	0.581	0.870	0.582	0.389
	1983-84	0.617	0.600	0.916	0.628	0.411
	1984-85	0.621	0.616	0.957	0.669	0.431
	1985-86	0.620	0.630	0.994	0.706	0.448
	1986-87	0.559	0.640	1.022	0.734	0.460
	1987-88	0.678	0.645	1.036	0.748	0.466
	1988-89	0.662	0.644	1.033	0.745	0.464
Southern	1975-76[1]	0.539	0.597	0.909	0.621	0.408
	1976-77[1]	0.499	0.564	0.830	0.542	0.368
	1977-78[1]	0.552	0.545	0.787	0.499	0.346
	1978-79[1]	0.553	0.536	0.768	0.480	0.335
	1979-80[1]	0.463	0.537	0.770	0.482	0.336
	1980-81	0.484	0.545	0.787	0.499	0.346
	1981-82	0.545	0.559	0.819	0.531	0.362
	1982-83	—	0.576	0.858	0.570	0.383
	1983-84	—	0.595	0.904	0.616	0.405
	1984-85	—	0.601	0.919	0.631	0.413
	1985-86	0.570	0.610	0.942	0.654	0.423
	1986-87	0.601	0.614	0.952	0.664	0.428
	1987-88	0.675	0.623	0.976	0.688	0.439
	1988-89	0.607	0.633	1.002	0.714	0.451

[1]Mortality rates from R. Hatch (U. S. Fish and Wildlife Service, personal communication).

Table 5.—Percentage of unclipped lake trout, by year class and station in the index catch, 1983-89.

Year class	Little Traverse Bay Area Percent unclipped	Little Traverse Bay Area Sample size	Grand Traverse Bay Percent unclipped	Grand Traverse Bay Sample size	Good Harbor Percent unclipped	Good Harbor Sample size	Platte Bay Percent unclipped	Platte Bay Sample size	Big and Little Sable Points Percent unclipped	Big and Little Sable Points Sample size	Muskegon-Whitehall Percent unclipped	Muskegon-Whitehall Sample size
1975	0.0	2	7.7	13	0.0	9	0.0	16	0.0	23	0.0	5
1976	0.0	8	15.0*	20	0.0	7	3.6	28	2.9	34	0.0	2
1977	0.0	11	4.7	64	4.2	24	0.0	49	3.1	65	0.0	8
1978	0.0	39	4.3	92	2.0	101	1.8	56	1.5	68	0.0	16
1979	1.0	97	3.7	216	2.5	199	3.8	105	1.1	92	0.0	30
1980	1.6	125	2.8	457	0.0	74	2.6	114	0.8	124	0.0	90
1981	0.0	118	8.9*	45	0.0	239	0.5	196	1.3	223	0.5	205
1982	2.2	134	1.5	777	0.4	973	2.6	391	2.9	561	0.8	852
1983	0.0	25	1.6	62	0.0	43	5.7*	53	0.7	303	0.4	274
1984	0.4	961	0.2	581	0.0	442	1.0	210	1.5	194	0.60	347
1985	0.4	227	1.0	195	2.2	226	0.0	89	3.8	158	0.0	131
1986	0.0	5	0.0	17	--	--	0.0	7	0.0	44	0.0	54

*Chi-square significant at the 5% probability level.

Table 6.—Percentage age composition and spawning frequency of hatchery-reared lake trout in Lake Michigan when the population equilibrates at two fishing rates and varying minimum size limits (MSL), by zone.

Zone	Mean fishing rate (F)[1]	MSL	Recruited age	Percentage ≥ age 6[3]		Spawning frequency		Years to equilibrium	
				Mean F	Target F[4]	Mean F	Target F	Mean F	Target F
Northern	1.051	537[2]	4.7	6.3	25.7	0.2	1.5	0	15
		559	5.0	8.0	26.7	0.3	1.8	7	15
		584	5.4	11.5	28.4	0.5	2.2	7	15
		610	5.8	16.9	30.4	1.0	2.7	7	15
		635	6.3	21.1	32.0	1.5	3.3	8	15
		660	6.8	24.5	33.6	2.3	4.1	8	16
		686	7.3	27.9	35.0	3.3	5.0	8	16
		711	7.9	30.8	36.9	4.4	5.9	9	16
Central	0.733	569[2]	5.2	13.8	27.6	0.7	1.9	0	14
		584	5.4	16.0	28.7	1.1	2.3	8	14
		610	5.9	20.8	30.8	1.8	2.8	8	15
		635	6.4	24.0	32.3	2.5	3.5	8	15
		660	6.9	27.3	33.9	3.7	4.4	9	15
		686	7.5	29.9	35.3	4.6	5.8	10	15
		711	8.1	32.6	36.6	5.0	6.1	10	16
Southern	0.680	595[2]	6.2	23.6	30.7	1.9	3.2	0	14
		610	6.5	25.1	31.6	2.3	3.6	8	14
		635	7.0	28.5	33.8	3.4	4.6	8	15
		660	7.5	30.5	34.6	4.1	5.3	9	15
		686	8.1	33.0	36.1	5.2	6.2	9	15
		711	8.9	34.9	36.4	6.1	7.0	10	15

[1]Mean instantaneous fishing rate during 1985-88.

[2]Mean length at recruitment during 1985-88.

[3]Population defined as ≥age-3 fish.

[4]Target F = 0.223.

Table 7.—Maximum egg production by hatchery-reared Lake Michigan when the population equilibrates at two fishing rates[1] and varying minimum size limits (MSL), by zone.

		Egg production (millions)		Years to equilibrium	
Zone	MSL	Mean F	Target F	Mean F	Target F
Northern	537	8.10	89.01	0	15
	559	11.30	95.47	7	15
	584	16.59	103.88	7	15
	610	25.67	114.21	7	15
	635	36.77	125.34	8	15
	660	52.68	138.38	8	16
	686	71.97	152.68	8	16
	711	95.38	167.98	9	16
Central	569	12.94	51.73	0	14
	584	15.40	54.55	8	14
	610	21.20	60.25	8	15
	635	27.73	66.26	8	15
	660	37.29	73.43	9	15
	686	47.03	80.99	9	15
	711	59.55	89.39	10	16
Southern	595	24.78	59.98	0	14
	610	28.80	63.53	8	14
	635	38.23	70.52	8	15
	660	46.34	77.13	9	15
	686	57.60	84.99	9	15
	711	68.61	92.85	10	15

[1]See Table 6 for F values.

Table 8.—Percentage age composition, spawning frequency, and egg production of lake trout in the northern zone at the target fishing rate in the same number of years required to reach equilibrium at the mean fishing rate.

	Target F = 0.223				Mean F = 1.051			
MSL	Percent ≥age 6	Spawning frequency per female	Egg production (millions)	Years	Percent ≥age 6	Spawning frequency per female	Egg production (millions)	Years to equilibrium
537	12.7	0.4	33.74	1	6.3	0.2	8.10	0
559	25.8	1.6	87.56	7	8.0	0.3	11.30	7
584	27.5	1.9	95.16	7	11.5	0.5	16.59	7
610	29.4	2.4	104.50	7	16.9	1.0	25.67	7
635	31.4	3.8	118.68	8	21.1	1.5	36.77	8
660	32.9	4.6	130.78	8	24.5	2.3	52.68	8
686	34.2	5.6	144.07	8	27.9	3.3	71.97	8
711	35.8	5.9	161.83	9	30.8	4.4	95.38	9

Table 9a.—Potential production of lake trout eggs per 113 km of Lake Michigan shoreline in the northern zone, by fishing rate and minimum size limit (MSL).

Fishing rate	In year	Egg production (millions) at MSL							
		537 mm	559 mm	584 mm	610 mm	635 mm	660 mm	686 mm	711 mm
1.051	1	4.9	5.0	6.0	7.6	9.1	10.7	12.1	13.0
	2	—	5.8	8.0	11.7	15.7	20.8	25.4	28.1
	3	—	6.5	9.3	14.2	20.0	28.1	36.6	44.5
	4	—	6.7	9.9	15.2	21.6	30.8	41.6	53.8
	5	—	6.8	10.0	15.5	22.2	31.7	43.2	56.8
	6	—	—	10.1	15.6	22.4	32.0	43.7	57.8
	7	—	—	—	15.7	22.4	32.1	43.9	58.0
	8	—	—	—	—	22.4	32.1	43.9	58.1
	9	—	—	—	—	—	—	—	58.2
	10	—	—	—	—	—	—	—	—
0.223	1	11.0	11.1	11.5	11.9	12.4	12.9	13.3	13.5
	2	20.6	21.0	22.4	24.0	25.7	27.6	29.0	29.9
	3	30.3	31.6	34.0	37.0	40.1	43.6	46.9	49.6
	4	38.0	40.1	43.4	47.4	51.7	56.6	61.6	66.4
	5	43.6	46.3	50.2	55.0	60.2	66.1	72.4	78.7
	6	47.4	50.5	54.9	60.2	65.9	72.6	79.7	87.1
	7	50.0	53.4	58.0	63.7	69.8	76.9	84.7	92.8
	8	51.5	55.5	60.1	66.0	72.4	79.7	87.8	96.4
	9	52.6	56.4	61.3	67.4	73.9	81.5	89.8	98.7
	10	53.3	57.1	62.2	68.3	75.0	82.6	91.1	100.2

Table 9b.—Potential production of lake trout eggs per 113 km of Lake Michigan shoreline in the central zone, by fishing rate and minimum size limit (MSL).

Fishing rate	In year	Egg production (millions) at MSL						
		569 mm	584 mm	610 mm	635 mm	660 mm	686 mm	711 mm
0.734	1	7.1	7.9	8.9	10.3	11.3	12.2	14.3
	2	7.5	9.5	11.7	15.0	17.3	20.4	23.2
	3	7.8	10.3	13.2	17.4	21.3	25.1	30.4
	4	7.9	10.7	13.9	18.5	23.1	27.2	33.9
	5	7.9	10.9	14.2	19.0	23.9	28.1	340.2
	6	8.0	10.9	14.3	19.2	24.2	28.5	35.9
	7	8.0	11.0	14.4	19.3	24.8	29.2	36.2
	8	8.0	11.0	14.4	19.3	24.4	28.7	36.3
	9	—	—	—	19.3	24.4	28.7	36.3
	10	—	—	—	—	—	—	36.3
0.223	1	10.7	10.9	11.2	11.6	12.1	12.5	12.8
	2	15.3	15.8	16.7	17.8	19.2	20.3	21.2
	3	19.0	19.7	21.3	23.0	25.1	27.1	29.0
	4	21.7	22.7	24.7	26.9	29.5	32.1	34.9
	5	23.5	24.7	27.0	29.5	32.5	35.6	38.9
	6	24.7	26.0	28.5	31.3	34.6	38.0	41.7
	7	25.5	26.8	29.5	32.4	35.9	39.4	43.4
	8	26.0	27.4	30.2	33.2	36.7	40.4	44.5
	9	26.3	27.7	30.6	33.6	37.2	41.0	45.2
	10	26.5	28.0	30.8	33.9	37.6	41.4	45.6

Table 9c.—Potential production of lake trout eggs per 113 km of Lake Michigan shoreline in the southern zone, by fishing rate and minimum size limit

Fishing rate	In year	Egg production (millions) at MSL					
		595 mm	610 mm	635 mm	660 mm	686 mm	711 mm
0.669	1	12.4	13.3	15.6	16.9	18.4	19.3
	2	—	13.9	17.5	20.2	23.9	25.9
	3	—	14.2	18.4	21.9	6.0	30.6
	4	—	14.3	18.8	22.6	27.9	32.8
	5	—	14.4	19.0	22.9	28.4	33.7
	6	—	14.4	19.1	23.1	28.7	34.0
	7	—	14.4	19.1	23.1	28.7	34.2
	8	—	14.4	19.1	23.2	28.8	34.3
	9	—	—	—	23.2	28.8	34.3
	10	—	—	—	—	—	34.3
0.223	1	21.0	21.5	22.6	23.3	24.0	24.4
	2	25.9	26.9	28.8	30.5	32.4	33.5
	3	29.5	30.9	33.5	36.0	38.8	41.2
	4	32.0	33.6	36.8	39.8	43.4	46.8
	5	33.7	35.5	39.1	42.4	46.4	50.1
	6	34.7	36.7	40.5	44.1	48.4	52.5
	7	35.4	37.5	41.5	45.2	49.7	54.0
	8	35.9	38.0	42.0	45.9	50.5	55.6
	9	36.2	38.3	42.4	46.4	51.0	55.9
	10	36.3	38.5	42.6	46.6	51.3	56.2

Table 10.—Harvest quotas (numbers) established for lake trout in eastern Lake Michigan and ratios of estimated actual F to target F (0.223), by year and zone.

Year	Statistic[1]	Zone			Total
		Northern	Central	Southern	
1984	Quota	23,911	13,609	19,269	56,789
	$F:F_{target}$	4.0:1	3.0:1	2.8:1	
1985	Quota	14,576	12,046	15,332	41,954
	$F:F_{target}$	4.3:1	3.2:1	2.9:1	
1986	Quota	14,831	11,893	15,253	41,977
	$F:F_{target}$	4.5:1	3.3:1	3.0:1	
1987	Quota	9,488	12,724	14,890	37,102
	$F:F_{target}$	4.8:1	3.4:1	3.1:1	
1988	Quota	29,156	6,915	14,075	50,146
	$F:F_{target}$	5.3:1	3.3:1	3.2:1	
1989	Quota	22,479	12,092	9,418	43,989
	$F:F_{target}$	—	—	—	

[1]F from Table 4.

Table 11.—Distribution of the lake trout harvest taken by sport and commercial fisheries from the northern zone of Lake Michigan.

Fishery	Yield (1,000s kg)[1]			
	1985	1986	1987	1988
Sport	94.1	53.3	33.5	57.5
Percent	30.6	43.9	24.6	33.0
Indian	213.3	99.3	102.7	116.9
Percent	69.4	65.1	75.4	67.0
Total	307.5	152.6	136.2	174.4

[1]Data from Technical Fisheries Review Committee (1989).

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Appendix A1.—Mean total length (mm), sample size, and instantaneous growth rates (total length) of lake trout in Lake Michigan's northern zone, by age class within year class.

Year class	Statistic	Age class III+	IV+	V+	VI+	VII+	VIII+	IX+	X+	XI+	XII+
1964	Mean length	—	—	—	—	—	—	—	—	—	—
	N	—	—	—	—	—	—	—	—	—	—
	Growth rate	—	—	—	—	—	—	—	—	—	—
1965	Mean length	—	—	—	—	—	—	—	—	876	849
	N	—	—	—	—	—	—	—	—	1	4
	Growth rate	—	—	—	—	—	—	—	—	-0.031	—
1966	Mean length	—	—	—	—	—	—	—	771	797	819
	N	—	—	—	—	—	—	—	5	24	6
	Growth rate	—	—	—	—	—	—	—	0.033	0.027	—
1967	Mean length	—	—	—	—	—	—	753	768	800	773
	N	—	—	—	—	—	—	3	17	4	2
	Growth rate	—	—	—	—	—	—	0.020	0.041	-0.034	—
1968	Mean length	—	—	—	—	—	768	766	782	829	785
	N	—	—	—	—	—	9	18	19	6	2
	Growth rate	—	—	—	—	—	-0.003	0.021	0.058	-0.055	—
1969	Mean length	—	—	—	—	665	709	731	796	763	794
	N	—	—	—	—	6	64	38	11	3	2
	Growth rate	—	—	—	—	0.064	0.031	0.085	-0.042	0.040	—
1970	Mean length	—	—	—	640	664	698	752	732	768	—
	N	—	—	—	20	167	74	13	10	2	—
	Growth rate	—	—	—	0.037	0.050	0.075	-0.027	0.048	—	—
1971	Mean length	—	—	580	635	667	724	750	823	—	—
	N	—	—	30	250	179	44	2	5	—	—
	Growth rate	—	—	0.091	0.049	0.082	0.035	0.093	—	—	—
1972	Mean length	—	493	569	633	662	—	686	787	802	—
	N	—	40	356	334	125	—	28	8	1	—
	Growth rate	—	0.143	0.107	0.045	—	—	0.137	0.019	—	—
1973	Mean length	366	491	567	630	662	703	758	771	882	—
	N	6	40	51	70	52	49	11	4	1	—
	Growth rate	0.294	0.144	0.105	0.050	0.060	0.075	0.017	0.135	—	—
1974	Mean length	397	545	580	632	661	738	768	—	—	752
	N	23	37	48	64	60	10	10	—	—	1
	Growth rate	0.317	0.062	0.086	0.045	0.110	0.040	—	—	—	—
1975	Mean length	329	453	549	624	680	719	819	—	—	772
	N	5	36	34	87	30	10	4	—	—	1
	Growth rate	0.320	0.192	0.128	0.086	0.056	0.130	—	—	—	—

Appendix A1.—Continued:

Year class	Statistic	Age class III+	IV+	V+	VI+	VII+	VIII+	IX+	X+	XI+	XII+
1976	Mean length	388	471	570	641	697	760	—	756	—	805
	N	20	24	105	72	19	6	—	2	—	1
	Growth rate	0.194	0.191	0.117	0.084	0.087	—	—	—	—	—
1977	Mean length	376	505	588	662	712	741	729	781	805	—
	N	10	76	66	50	10	5	12	4	2	—
	Growth rate	0.295	0.152	0.119	0.073	0.040	-0.016	0.069	0.030	—	—
1978	Mean length	401	483	570	644	702	712	732	825	—	—
	N	14	26	67	39	24	9	8	1	—	—
	Growth rate	0.186	0.166	0.122	0.086	0.014	0.028	0.120	—	—	—
1979	Mean length	388	502	577	651	665	683	735	—	—	—
	N	12	88	103	114	36	19	5	—	—	—
	Growth rate	0.258	0.139	0.121	0.021	0.027	0.073	—	—	—	—
1980	Mean length	399	497	565	631	667	709	729	—	—	—
	N	141	121	171	109	91	17	12	—	—	—
	Growth rate	0.220	0.128	0.110	0.055	0.061	0.028	—	—	—	—
1981	Mean length	408	520	589	623	750	673	—	—	—	—
	N	31	51	69	65	6	18	—	—	—	—
	Growth rate	0.243	0.125	0.056	0.186	-0.108	—	—	—		
1982	Mean length	380	507	578	614	661	—	—	—	—	—
	N	164	184	393	196	145	—	—	—	—	—
	Growth rate	0.288	0.131	0.060	0.074	—	—	—	—	—	—
1983	Mean length	370	604	554	620	—	—	—	—	—	—
	N	29	2	29	26	—	—	—	—	—	—
	Growth rate	0.490	-0.086	0.113	—	—	—	—	—	—	—
1984	Mean length	431	502	583	—	—	—	—	—	—	—
	N	211	804	563	—	—	—	—	—	—	—
	Growth rate	0.152	0.150	—	—	—	—	—	—	—	—
1985	Mean length	407	504	—	—	—	—	—	—	—	—
	N	101	319	—	—	—	—	—	—	—	—
	Growth rate	0.214	—	—	—	—	—	—	—	—	—

Appendix A2.—Mean total length (mm), sample size, and instantaneous growth rates (total length) of lake trout in Lake Michigan's central zone, by age class within year class.

Year class	Statistic	Age class III+	IV+	V+	VI+	VII+	VIII+	IX+	X+	XI+	XII+
1964	Mean length	—	—	—	—	—	—	—	—	—	—
	N	—	—	—	—	—	—	—	—	—	—
	Growth rate	—	—	—	—	—	—	—	—	—	—
1965	Mean length	—	—	—	—	—	—	—	—	808	—
	N	—	—	—	—	—	—	—	—	1	—
	Growth rate	—	—	—	—	—	—	—	—	—	—
1966	Mean length	—	—	—	—	—	—	—	785	806	—
	N	—	—	—	—	—	—	—	8	6	—
	Growth rate	—	—	—	—	—	—	—	0.026	—	—
1967	Mean length	—	—	—	—	—	—	752	763	768	809
	N	—	—	—	—	—	—	32	32	9	7
	Growth rate	—	—	—	—	—	—	0.015	0.007	0.052	—
1968	Mean length	—	—	—	—	—	721	751	766	788	778
	N	—	—	—	—	—	47	39	10	3	15
	Growth rate	—	—	—	—	—	0.041	0.020	0.028	-0.013	—
1969	Mean length	—	—	—	—	698	714	761	775	783	819
	N	—	—	—	—	35	51	84	22	12	9
	Growth rate	—	—	—	—	0.023	0.064	0.018	0.010	0.045	—
1970	Mean length	—	—	—	646	675	729	735	759	781	886
	N	—	—	—	31	73	96	35	36	26	1
	Growth rate	—	—	—	0.044	0.077	0.008	0.032	0.029	0.126	—
1971	Mean length	—	—	598	647	712	748	757	795	853	—
	N	—	—	39	68	101	64	40	27	5	—
	Growth rate	—	—	0.079	0.096	0.049	0.012	0.049	0.070	—	—
1972	Mean length	—	506	588	670	685	716	754	811	853	831
	N	—	78	161	283	157	131	78	6	2	2
	Growth rate	—	0.150	0.131	0.022	0.044	0.052	0.073	0.050	-0.026	—
1973	Mean length	420	492	609	658	674	718	759	826	—	—
	N	20	246	198	153	144	130	20	6	—	—
	Growth rate	0.158	0.213	0.077	0.024	0.063	0.056	0.085	—	—	—
1974	Mean length	407	526	585	603	676	690	800	801	—	750
	N	52	41	140	677	93	35	8	4	—	1
	Growth rate	0.256	0.106	0.030	0.114	0.020	0.148	0.001	—	—	—
1975	Mean length	396	522	551	625	663	725	767	815	729	785
	N	5	132	683	548	118	25	6	2	9	3
	Growth rate	0.276	0.054	0.126	0.059	0.089	0.056	0.061	-0.112	0.074	—

Appendix A2.—Continued:

Year class	Statistic	Age class III+	IV+	V+	VI+	VII+	VIII+	IX+	X+	XI+	XII+
1976	Mean length	370	480	552	616	707	739	787	720	771	—
	N	1	238	345	89	29	9	10	1	3	—
	Growth rate	0.260	0.140	0.110	0.138	0.044	0.063	-0.089	0.068	—	—
1977	Mean length	391	482	547	656	684	755	769	773	771	830
	N	57	227	215	81	16	10	9	16	2	1
	Growth rate	0.209	0.127	0.182	0.042	0.099	0.018	0.005	-0.003	0.074	—
1978	Mean length	403	483	595	657	712	684	760	781	769	—
	N	145	179	97	55	50	15	17	10	6	—
	Growth rate	0.181	0.209	0.099	0.080	-0.040	0.105	0.027	-0.015	—	—
1979	Mean length	379	491	588	663	656	722	765	777	—	—
	N	149	220	150	103	22	38	11	6	—	—
	Growth rate	0.259	0.180	0.120	-0.011	0.096	0.058	0.016	—	—	—
1980	Mean length	391	511	566	594	658	710	720	—	—	—
	N	211	101	135	50	46	30	37	—	—	—
	Growth rate	0.268	0.102	0.048	0.102	0.076	0.014	—	—	—	—
1981	Mean length	429	500	544	613	678	702	—	—	—	—
	N	78	158	156	115	90	123	—	—	—	—
	Growth rate	0.153	0.084	0.119	0.101	0.035	—	—	—		
1982	Mean length	382	465	558	620	670	—	—	—	—	—
	N	165	686	528	344	279	—	—	—	—	—
	Growth rate	0.197	0.182	0.105	0.078	—	—	—	—	—	—
1983	Mean length	380	467	548	631	—	—	—	—	—	—
	N	96	22	48	39	—	—	—	—	—	—
	Growth rate	0.206	0.160	0.141	—	—	—	—	—	—	—
1984	Mean length	378	498	589	—	—	—	—	—	—	—
	N	185	379	287	—	—	—	—	—	—	—
	Growth rate	0.276	0.168	—	—	—	—	—	—	—	—
1985	Mean length	401	502	—	—	—	—	—	—	—	—
	N	199	260	—	—	—	—	—	—	—	—
	Growth rate	0.225	—	—	—	—	—	—	—	—	—

Appendix A3.—Mean total length (mm), sample size, and instantaneous growth rates (total length) of lake trout in Lake Michigan's southern zone, by age class within year class.

Year class	Statistic	Age class III+	IV+	V+	VI+	VII+	VIII+	IX+	X+	XI+	XII+
1975	Mean length	—	—	—	—	—	—	—	—	760	742
	N	—	—	—	—	—	—	—	—	2	1
	Growth rate	—	—	—	—	—	—	—	—	-0.024	—
1978	Mean length	—	—	—	—	—	677	725	746	752	—
	N	—	—	—	—	—	5	6	2	2	—
	Growth rate	—	—	—	—	—	0.069	0.029	0.008	—	—
1979	Mean length	—	—	—	—	662	709	751	755	—	—
	N	—	—	—	—	8	9	3	4	—	—
	Growth rate	—	—	—	—	0.069	0.058	0.005	—	—	—
1980	Mean length	—	—	—	610	656	683	719	—	—	—
	N	—	—	—	33	26	22	12	—	—	—
	Growth rate	—	—	—	0.073	0.040	0.051	—	—	—	—
1981	Mean length	—	—	551	572	626	672	—	—	—	—
	N	—	—	73	66	25	44	—	—	—	—
	Growth rate	—	—	0.037	0.090	0.071	—	—	—	—	—
1982	Mean length	—	462	515	582	629	—	—	—	—	—
	N	—	47	405	125	82	—	—	—	—	—
	Growth rate	—	0.109	0.122	0.078	—	—	—	—	—	—
1983	Mean length	417	453	507	625	—	—	—	—	—	—
	N	5	63	25	28	—	—	—	—	—	—
	Growth rate	0.083	0.113	0.209	—	—	—	—	—	—	—
1984	Mean length	387	437	539	—	—	—	—	—	—	—
	N	142	46	47	—	—	—	—	—	—	—
	Growth rate	0.122	0.210	—	—	—	—	—	—	—	—
1985	Mean length	393	470	—	—	—	—	—	—	—	—
	N	86	120	—	—	—	—	—	—	—	—
	Growth rate	0.179	—	—	—	—	—	—	—	—	—

Appendix B1.—Maturity-at-age schedule of lake trout in Lake Michigan in 1983-89. Sample size is given in parentheses.

Age group	Percent mature	
	Males	Females
2	0.0 (52)	0.0 (45)
3	0.4 (958)	0.2 (892)
4	5.6 (1,918)	1.2 (1,707)
5	42.0 (1,715)	27.2 (1,623)
6	74.1 (780)	71.0 (844)
7	92.7 (467)	87.4 (533)
8	96.8 (3.5)	94.8 (192)
9	100.0 (85)	98.8 (85)
10	100.0 (43)	100.0 (18)

Appendix B2.—Estimated von Bertalanffy growth parameters of lake trout caught in graded-mesh gill nets fished during the spring, by zone and year.

Zone	Year	K	L∞	t_o
Northern	1984	0.13	1,181	-0.01
	1985	0.13	1,137	-0.003
	1986	0.19	912	0.10
	1987	0.17	983	0.03
	1988	0.19	915	0.04
	1989	0.20	865	0.03
Central	1984	0.18	970	0.03
	1985	0.14	1,125	0.01
	1986	0.19	883	0.10
	1987	0.18	935	0.03
	1988	0.19	915	0.05
	1989	0.20	879	0.05
Southern	1984	—	—	—
	1985	—	—	—
	1986	0.16	953	0.07
	1987	0.15	953	0.15
	1988	0.16	967	0.04
	1989	0.18	887	-0.006

Appendix C.—Estimated standing stock in number of lake trout in Lake Michigan, by zone. Plants were standardized to yearling equivalents when necessary.

Age group	1984 Stock	1984 Survival	1985 Stock	1985 Survival	1986 Stock	1986 Survival	1987 Stock	1987 Survival	1988 Stock	1988 Survival	1989 Stock
					Northern Zone						
1	61,600	0.400	1,030,800	0.400	194,800	0.400	60,000	0.400	227,400	0.400	—
2	151,080	0.590	24,640	0.590	412,320	0.590	77,920	0.590	24,000	0.590	90,960
3	24,261	0.750	89,137	0.750	14,538	0.750	243,269	0.750	45,973	0.750	14,160
4	82,765	0.817	18,196	0.817	66,853	0.817	10,903	0.817	182,452	0.817	34,480
4.7	67,654	0.700	14,874	0.690	54,647	0.678	8,913	0.664	149,140	0.645	0
5	45,075	0.305	47,379	0.290	10,260	0.274	37,059	0.255	5,915	0.232	96,214
6	13,539	0.305	13,748	0.290	13,740	0.274	2,811	0.255	9,450	0.232	1,372
7	7,142	0.305	4,129	0.290	3,987	0.274	3,765	0.255	717	0.232	2,192
8	2,159	0.305	2,178	0.290	1,198	0.274	1,092	0.255	960	0.232	166
9	650	0.305	658	0.290	632	0.274	328	0.255	279	0.232	223
10	261	0.305	198	0.290	191	0.274	173	0.255	84	0.232	65
11	115	0.305	80	0.290	57	0.274	52	0.255	44	0.232	19
12	26	0.305	35	0.290	23	0.274	16	0.255	13	0.232	10
13	12	0.305	8	0.290	10	0.274	6	0.255	4	0.232	3
14+	—	0.305	4	0.290	2	0.274	3	0.255	2	0.232	1
	—	—	—	0.290	1	0.274	1	0.255	1	0.232	0
Total ≥ age 4.7	136,633		83,291		84,748		54,219		166,608		100,267

Appendix C.—Continued:

Age group	1984 Stock	1984 Survival	1985 Stock	1985 Survival	1986 Stock	1986 Survival	1987 Stock	1987 Survival	1988 Stock	1988 Survival	1989 Stock
Central Zone											
1	80,000	0.400	432,600	0.400	219,800	0.400	36,900	0.400	130,000	0.400	—
2	143,680	0.590	32,000	0.590	173,040	0.590	87,920	0.590	14,760	0.590	52,000
3	74,552	0.750	84,771	0.750	18,880	0.750	102,094	0.750	51,873	0.750	8,708
4	50,463	0.750	55,914	0.750	63,578	0.750	14,160	0.750	76,570	0.750	38,905
5	42,374	0.944	37,847	0.944	41,936	0.944	47,684	0.944	10,620	0.944	57,428
5.2	40,002	0.465	35,729	0.451	39,588	0.442	45,015	0.437	10,026	0.438	54,213
6	22,114	0.384	18,601	0.370	16,128	0.360	17,483	0.355	19,658	0.356	4,388
7	9,180	0.384	8,492	0.370	6,883	0.360	5,806	0.355	6,206	0.356	6,998
8	3,601	0.384	3,525	0.370	3,142	0.360	2,478	0.355	2,061	0.356	2,209
9	1,893	0.384	1,383	0.370	1,304	0.360	1,131	0.355	880	0.356	734
10	599	0.384	727	0.370	512	0.360	470	0.355	402	0.356	313
11	172	0.384	230	0.370	269	0.360	184	0.355	167	0.356	143
12	128	0.384	66	0.370	85	0.360	97	0.355	65	0.356	59
13	60	0.384	49	0.370	24	0.360	31	0.355	34	0.356	23
14	18	0.384	23	0.370	18	0.360	9	0.355	11	0.356	12
15	—	0.384	7	0.370	9	0.360	7	0.355	3	0.356	4
	—	—	—	0.370	—	—	—	—	—	—	—
Total ≥ age 5.2	77,767		68,832		67,962		72,709		39,513		69,096

Appendix C.—Continued:

Age group	1984 Stock	1984 Survival	1985 Stock	1985 Survival	1986 Stock	1986 Survival	1987 Stock	1987 Survival	1988 Stock	1988 Survival	1989 Stock
Southern Zone											
1	220,000	0.400	139,500	0.400	527,900	0.400	0	0.400	270,000	0.400	—
2	189,400	0.590	88,000	0.590	55,800	0.590	211,160	0.590	0	0.590	108,000
3	119,038	0.750	111,746	0.750	51,920	0.750	32,922	0.750	124,584	0.750	0
4	93,934	0.750	89,279	0.750	83,810	0.750	38,940	0.750	24,692	0.750	93,438
5	54,428	0.750	70,451	0.750	66,959	0.750	62,857	0.750	29,205	0.750	18,519
6	67,700	0.944	40,821	0.944	52,838	0.944	50,219	0.944	47,143	0.944	21,904
6.2	63,909	0.479	38,536	0.471	49,880	0.467	47,408	0.458	44,504	0.448	20,678
7	30,171	0.399	30,644	0.390	18,143	0.386	23,292	0.377	21,723	0.367	19,959
8	9,129	0.399	12,038	0.390	11,951	0.386	7,003	0.377	8,781	0.367	7,972
9	4,328	0.399	3,642	0.390	4,695	0.386	4,613	0.377	2,640	0.367	3,223
10	1,957	0.399	1,727	0.390	1,421	0.386	1,812	0.377	1,739	0.367	969
11	378	0.399	781	0.390	673	0.386	548	0.377	683	0.367	638
12	185	0.399	151	0.390	305	0.386	260	0.377	207	0.367	251
13	33	0.399	74	0.390	59	0.386	118	0.377	98	0.367	76
14	17	0.399	13	0.390	29	0.386	23	0.377	44	0.367	36
15	—	—	7	0.390	5	0.386	11	0.377	9	0.367	16
Total ≥ age 6.2	110,107		87,613		87,161		85,088		80,429		53,818