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

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Abstract.—The objectives of the study were to determine the survival rate of hatchery-reared lake trout (*Salvelinus namaycush*) stocked as yearlings in the West Arm of Grand Traverse Bay, Lake Michigan during the 10-day period following planting, and the annual survival rate as 1-, 2-, and 3-year-old fish. Average survival of the yearling lake trout during the 10-day period following planting was estimated to have been 68%, which included removals by experimental fishing. The annual survival rate (including post-planting losses) of yearlings was determined to have averaged 40%. For 2-year-old lake trout the mean annual survival rate was estimated to have been 59%. The annual survival rate of 3-year-old lake trout could not be determined because 4-year-old lake trout were not fully vulnerable to the trawl. In the West Arm of Grand Traverse Bay, lake trout planted as fall fingerlings survived to 2 years of age at one-half the rate of the same year class planted as spring yearlings.

In settling the fishing dispute between Indian tribes and the State of Michigan, rulings issued by the federal court in 1979 and the 1985 consent agreement mandated management of lake trout (*Salvelinus namaycush*) by catch quotas. The consent agreement also stipulated that lake trout stocks in areas designated as high priority rehabilitation zones would be managed to maximize the reproductive potential of the species. The number of catchable lake trout is an essential statistic in the computation of catch quotas. Because stocks of lake trout in Lake Michigan are sustained by planting known numbers of hatchery-reared fish, estimates of standing stocks can be calculated when annual survival rate at each age is known. Although survival rates of the fishable portion of the stocks have been estimated, those for the pre-recruited segment have not. The objectives of this study were to determine the survival rate of hatchery-reared yearling lake trout in the West Arm of Grand Traverse Bay, Lake Michigan, during the 10-day period following planting, and the annual survival rate as 1-, 2-, and 3-year-old fish.

Methods

Study area.—The West Arm of Grand Traverse Bay, Lake Michigan (Figure 1) was selected as the study area because: (1) much of the area was trawlable; (2) the size and configuration of the basin maximized the probability that the juvenile lake trout could be tracked for a suitable time period; (3) there was a typical predator population; and (4) the basin was well protected from prevailing westerly winds, which minimized lost sampling opportunity caused by storms.

The West Arm of Grand Traverse Bay is approximately 29 km long and 5-7 km wide. The West Arm is essentially oligotrophic but has a wide variety of habitat. The southern end is relatively shallow and is ringed by beds of *Chara* spp. Progressing northward, the West Arm becomes deeper (maximum of 101 m), the inshore banks precipitous, and the substrate rocky.

The West Arm also has a wide variety of fish fauna. The predominant resident species are yellow perch (*Perca flavescens*), lake trout, lake whitefish (*Coregonus clupeaformis*), bloater (*Coregonus hoyi*), alewife (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), burbot (*Lota lota*), slimy sculpin (*Cottus cognatus*), channel catfish (*Ictalurus punctatus*), and trout-perch (*Percopsis omiscomaycus*).

Fishing gear.—To capture the stocked pre-recruits, an otter trawl (26.6 m long, head rope of 12.2 m, cod-end liner of 25.4 mm) was used. The bottom trawl was towed at approximately 4.8 knots.

Sampling design.—Sixteen trawling transects ($-T_1$, T_0, T_1, ..., T_{14}) were positioned approximately 1.6 km apart in the West Arm from the south end to Suttons Point (Figure 1). All transects were initially located by LORAN coordinates and then marked by buoys in the event the LORAN signal subsequently failed. The number of experimental lake trout planted annually ranged from 52,000 to 65,000 yearlings that were uniquely fin clipped to identify each year class. These were stocked in mid-May of each year during 1984-88 at the Traverse City Power Company's coal dock in Greilickville.

Trawling was done daily for 10 successive days beginning on the day after stocking. The selection of a 10-day sampling period was somewhat arbitrary. Presumably, most mortality caused by disease or stress would occur within that time frame.

The number of transects trawled each day depended upon where the yearling lake trout were found. For example, if yearlings were found at transect T_3, then trawling was advanced to transect T_4. If none were found at transect T_4, then trawling was terminated at that point; however, trawling on successive days was always completed to where the previous day's work had stopped. Trawling always began at transect $-T_1$ on the western side, progressed northward to the last transect (as previously defined), thence across the bay to the east shore and southward to transect T_0 (transect $-T_1$ on the east side was not trawlable because of pound-net stakes and debris). Trawling commenced at the inshore end of the transect at a depth of 2 m, across the contour, and continued for 10 minutes. With the exception of transect $-T_1$, which was rather shallow, a 10-minute tow covered maximum depths of from 55 m to 91 m. Since the trawling was across the contour, the depth distribution of the yearling trout could not be determined. However, trawling at various contours on the fifth day in 1984 captured no yearling lake trout deeper than 15 m.

Data analyses.—The analytical design to estimate post-planting survival was suggested by G. Eck (U. S. Fish and Wildlife Service, National Fisheries Research Center—Great Lakes, personal communication). To account for a shift in the daily distribution of the yearling lake trout along the transects, the catch per trawling hour for each day was plotted on the transects $-T_1$ to T_5 (beyond which no yearling trout were found), the curve smoothed by the best fitting regression model, and the area under the smoothed curve computed. Because the number of yearling lake trout stocked in each year ranged from 52,000 to 65,000, the catch of each year class was weighted by a base stocking of 65,000.

Survival rate, unadjusted for mortality caused by experimental fishing, for the 10-day period was estimated from the relation Y_{10}/Y_1, where Y_1 is the predicted percent of the curve area on day 1 and Y_{10} the predicted percent on day 10. The experimental fishing-induced mortality was calculated from the relation $C/N = F{\cdot}A/Z$, where C is the experimental catch, N is the number planted, F is the unknown instantaneous fishing rate, A is the 10-day total mortality, and Z is the instantaneous rate of total mortality for the 10-day period (Ricker 1975). The conditional natural mortality rate (n) for the 10-day period is then $n = 1-e^{-(Z-F)}$, and survival rate adjusted for removal by experimental fishing is $e^{-(Z-F)}$.

To estimate annual survival rate, trawling range was extended to transects T_6 through T_{14} at the end of the 10-day period to include the habitat of 2- and 3-year-old lake trout. Each of these transects was fished twice in May of each year. The total catch of 1-, 2-, and 3-year-old lake trout in each year over all days was standardized to catch per trawling hour per transect and number of each year class weighted for stocking density, which also was converted to area under the catch-transect curve. Estimates of annual survival rates required that catch be standardized to catch per trawling hour to equalize variations in fishing effort among transects. To estimate survival rate, a catch curve was constructed from age classes and their corresponding curve areas.

Results and Discussion

Post-Planting Survival Rate

Lake trout stocked in 1985 were captured in greater quantity (mean catch of 678.4) than those released in 1986 (mean catch of 226.4) and 1988 (mean catch of 186.8; Table 1). The catches in 1985 tended to be much greater at transects -T_1 and T_2, presumably because of *Chara* beds at those stations. However, it did not take long for the *Chara* beds to become depleted in the area of the trawled transects, which coincided with smaller catches of yearling lake trout. Although not quantified, the yield of *Chara* in the trawl dropped dramatically after 1985 and apparently had not recovered by 1989.

When the areas under the curves are expressed as a daily percentage of the total area for the year (Table 1), the results for the 3 years are similar (Figure 2). By regressing the square root transformation of the percent area (pooled for 1985, 1986, and 1988) on days ($P = 0.05$), survival rate adjusted for fishing rate ($F = 0.024$) is determined to be 68%. The advantages of the percentage transformation are that all data are used, and survival rate is represented by a single catch curve.

Conceivably, survival rate may have been biased downward because of several potential sources of sampling error. The transects may have been too far apart to intercept the yearling trout as they dispersed, thus underestimating relative abundance on successive days. Migration by the yearlings out of the study area also would have underestimated relative abundance on successive days. However, migration did not appear to be a source of bias in estimating survival rate. The yearling lake trout did not disperse rapidly or far within the 10 days after planting. Relatively few yearling lake trout were captured at transects T_1 through T_5 (1.6-8 km from the planting site T_0) and none were found beyond T_5 (Figure 3). The yearling trout appeared to be particularly attracted to the *Chara* beds which ring the south end of the West Arm. Undoubtedly the weed beds provided safe haven and abundant food for the young trout. The yearlings' range likely expanded considerably after several months. Trawling records from an unrelated study in 1983 (MDNR, unpublished) showed that yearling lake trout planted in May of that year at transect T_0 had dispersed widely along both shorelines of the West Arm northward to transect T_6 by September. Despite the potential biases, the 68% survival rate may have been caused in part by predation by burbot upon the yearling lake trout. Burbot that were caught at transects T_0 and T_1 consumed yearling lake trout in numbers which ranged from 1-38 per stomach. Predictably, examination of stomachs from burbot caught at transects T_2-T_5 rarely revealed yearling lake trout, although the burbot had fed extensively on smelt, alewife, and bloater. Cannibalism by older lake trout was virtually nonexistent.

Annual Survival Rates

Average rates of annual survival, excluding the loss during the 10-day post-planting period, of 1- and 2-year-old lake trout was estimated to be 59% (Figure 4). When the 10-day post-planting mortality rate (32%) is taken into account, the annual survival of 1-year-olds drops to 40%. In the absence of data on survival rates, past standing stock estimates of 1-, 2-, and 3-year-old lake trout were based on educated guesses of annual survival rates of 45% for 1-year olds, 60% for 2-year olds, and 70% for 3-year olds (R. Hatch, U. S. Fish and Wildlife Service, National Fisheries Research Center—Great Lakes, personal communication). Survival rate of 3-year-old lake trout could not be determined because so few 4-year-old fish were captured in the trawl, which presumably was due to gear avoidance and migration from the study area. Neither could survival rate be calculated from the age frequencies of 3- and 4-year-old lake trout caught in graded-mesh gill nets, because neither age group was fully vulnerable to the gear. The size distribution of

3-year-old trout caught in graded-mesh gill nets, which were used to index the subadult and the adult portion of the population (Rybicki 1990), was significantly skewed to the right ($P = 0.01$), and lacked the smaller members of the group that were caught in the trawl. Since it was unlikely that 3-year-old lake trout were consumed by piscivores in significant quantities, were too small for lamprey depredation, and usually were too small for the fishery, it is reasonable to presume that total mortality was at least as small as the 25% annual natural mortality rate estimated for lake trout 5-years old and older (Rybicki and Keller 1978).

Migration of 2- and 3-year-old lake trout from the study area does not appear to be an important source of bias in the survival estimates. The distribution of these two age classes along the transects showed that more than 90% of each age group was captured at transects T_0 through T_8 (Figure 5).

The trawl did not appear to be size selective for 2- and 3-year-old lake trout. Gear selectivity would have negatively biased the survival estimate because of the larger fishes' presumed ability to outswim the trawl. The length frequencies of 2- and 3-year-old lake trout captured in the trawl did not differ significantly ($P = 0.99$) from expected normalized frequencies (Figure 6).

Plants of Fall Fingerlings versus Spring Yearling

An opportunity occurred to compare survival indices of the 1982 year class of lake trout planted as fall fingerlings and as spring yearlings. Although not a part of this study, substantial numbers of those two groups of lake trout were subsequently caught while trawling for yearling lake trout in 1984.

In September, 1982, 111,000 fingerlings (averaging 60/kg, 134 mm total length) and in May 1983, 78,900 yearlings (averaging 46/kg, 146 mm total length) were stocked in the West Arm of Grand Traverse Bay. The survival index, defined as the number caught per number planted for each group, was 0.6% for the fall fingerlings and 1.3% for the spring yearlings. Contingency table analysis produced a highly significant chi-square ($P = 0.001$), which indicated that the survival index was strongly dependent upon the size or month the lake trout were planted. Thus, from equal numbers planted, one could expect about twice as many spring yearlings to survive to 2 years of age than those stocked as fall fingerlings.

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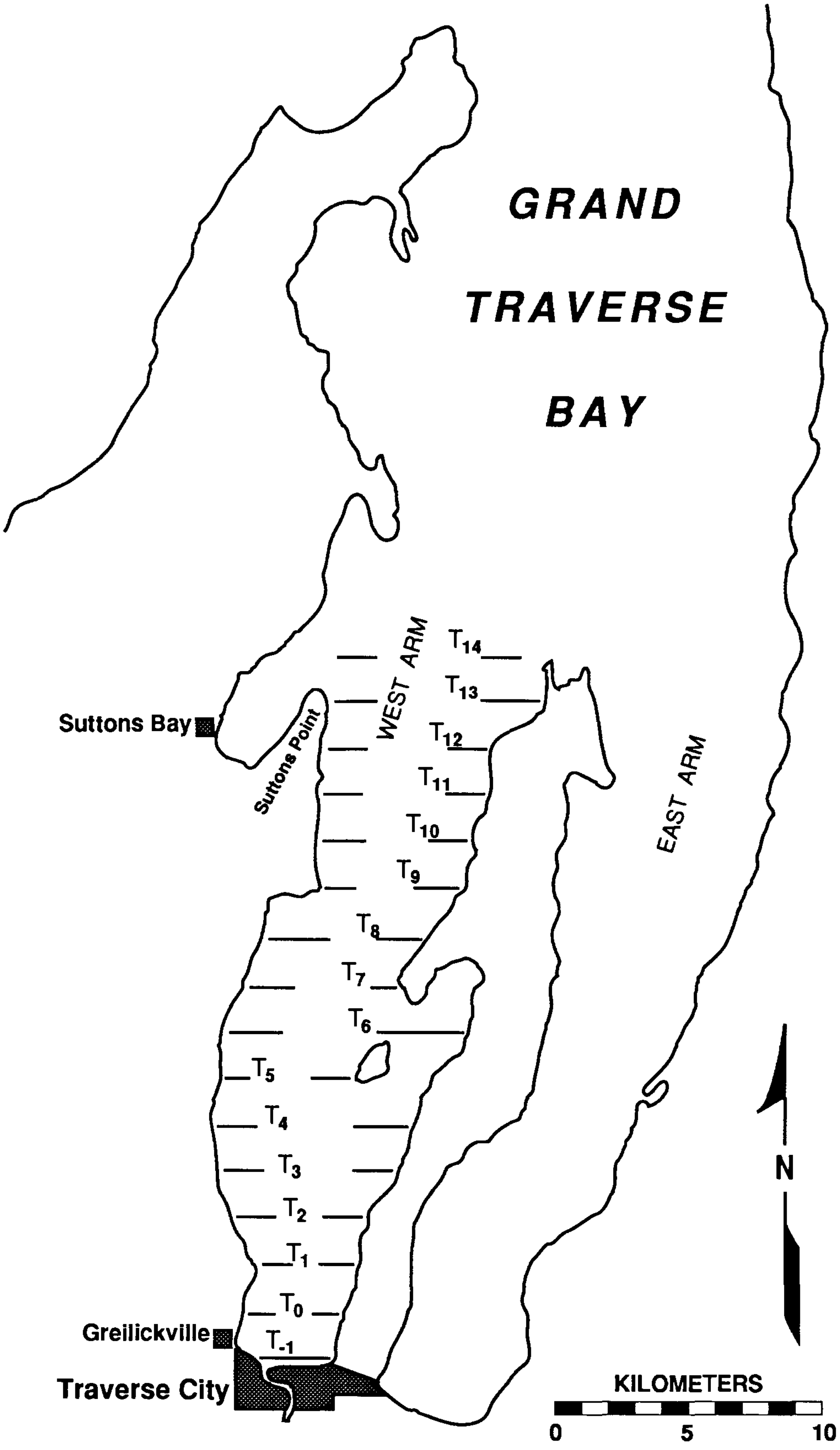

Figure 1.—Location of transects trawled in the West Arm of Grand Traverse Bay, Lake Michigan.

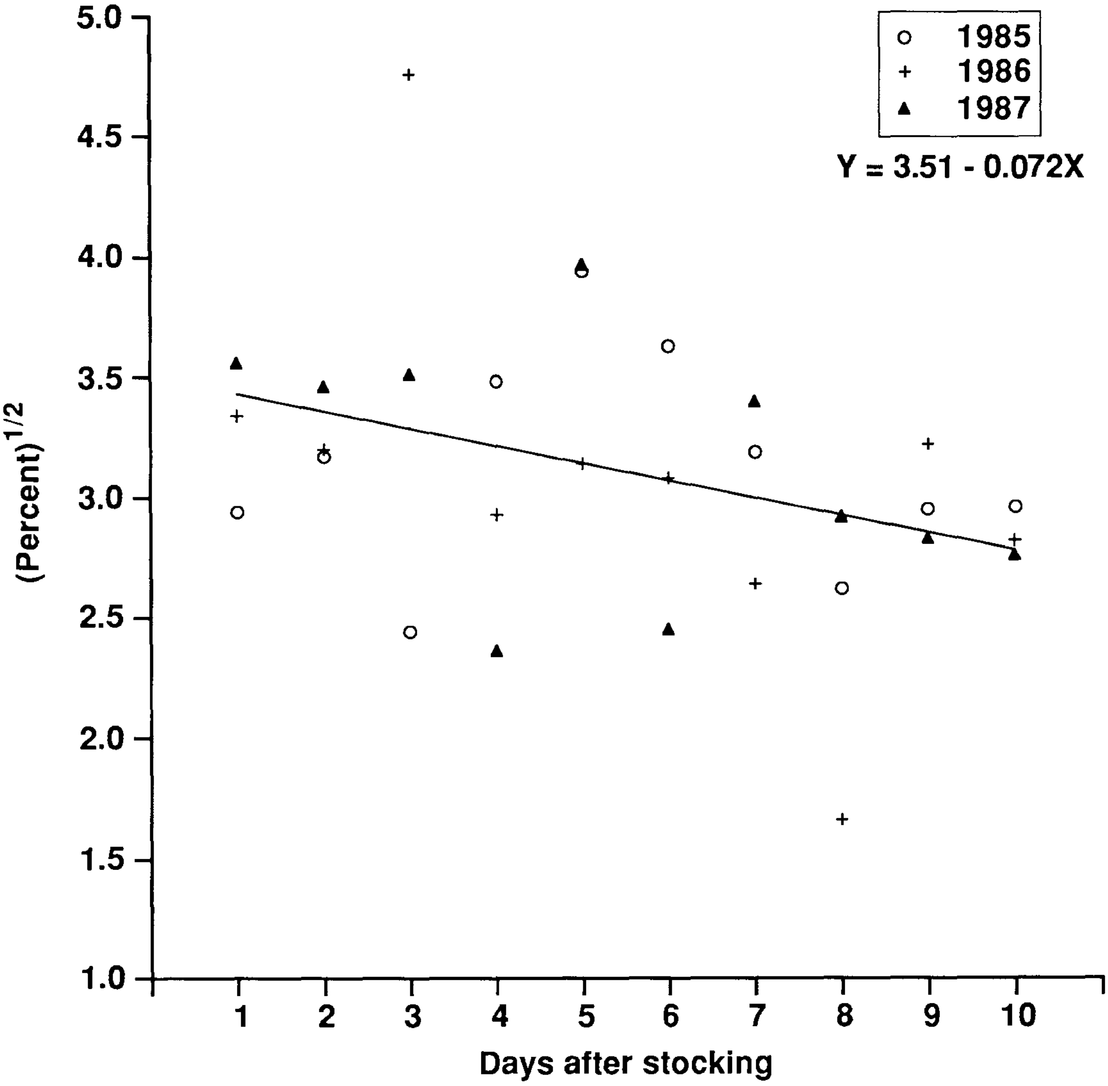

Figure 2.—Catch curve of yearling lake trout during the 10 days following stocking in the West Arm of Grand Traverse Bay in May of 1985, 1986, and 1988. The points indicate the square root transformation of daily curve areas expressed as percentages of the total. The regression line is based on pooling the three data sets.

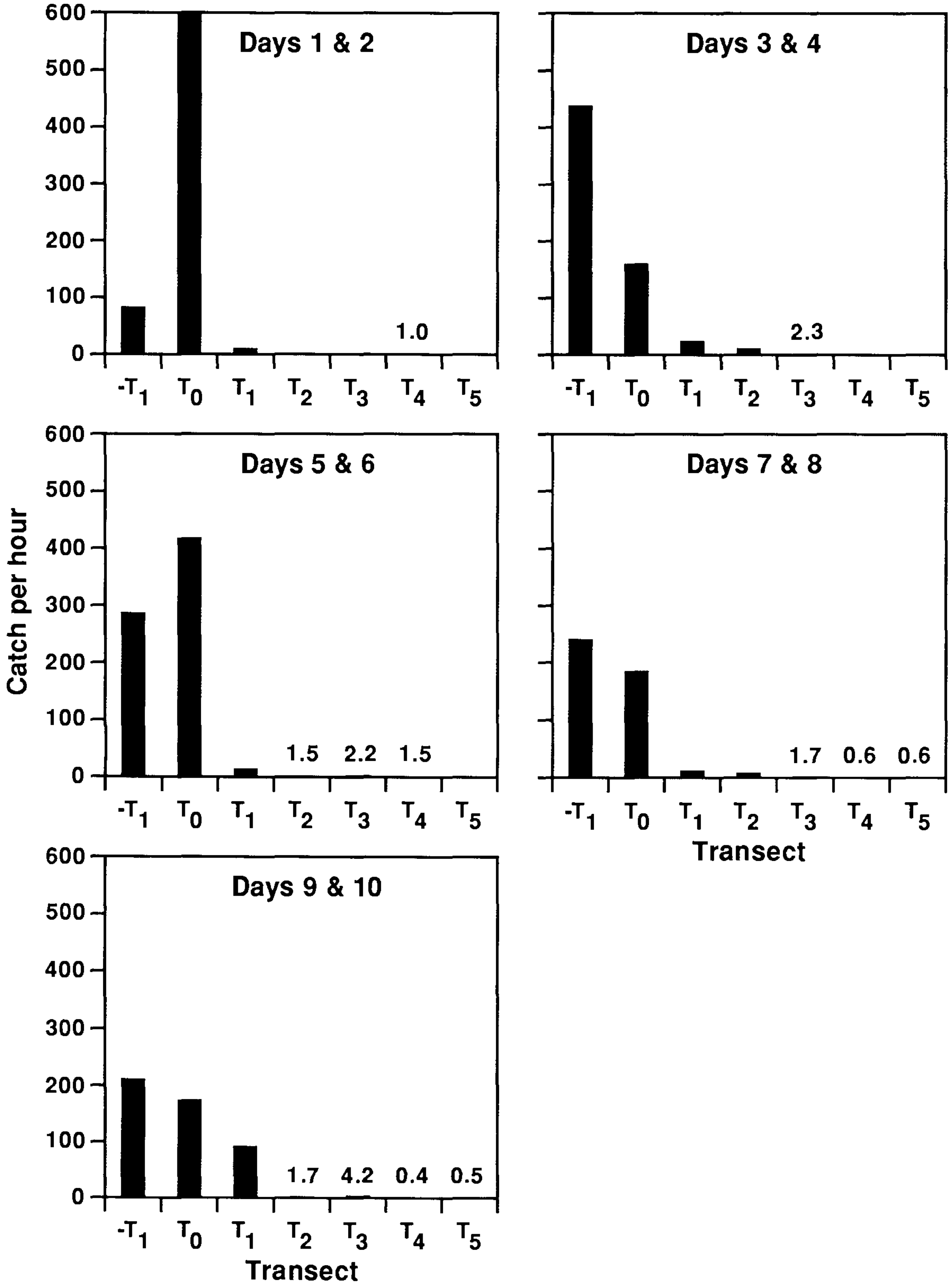

Figure 3.—Mean catch per trawling hour of yearling lake trout planted at transect T_0 in the West Arm of Grand Traverse Bay in May of 1985, 1986, and 1988.

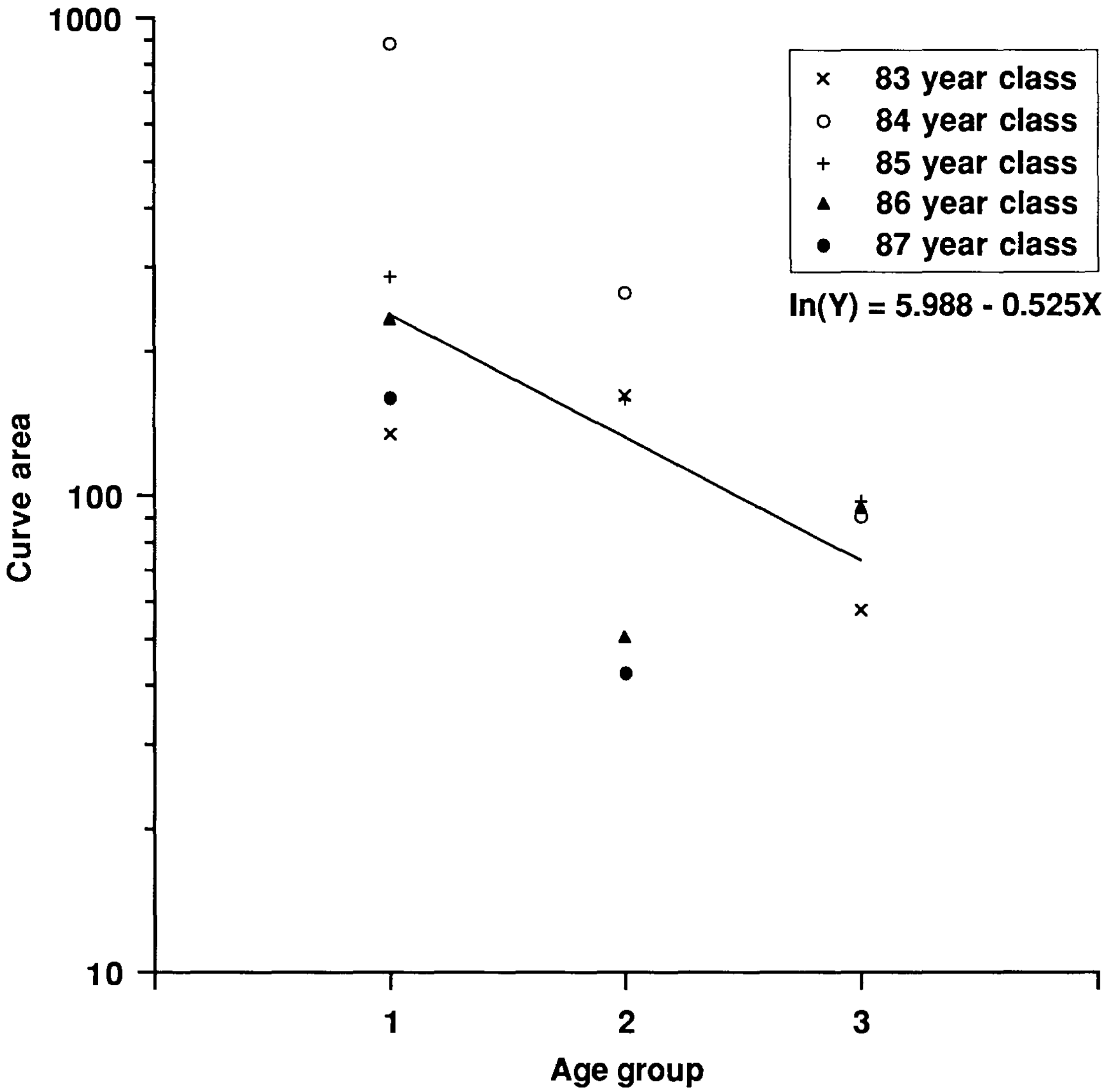

Figure 4.—Catch curve of lake trout stocked in the West Arm of Grand Traverse Bay, 1985-88.

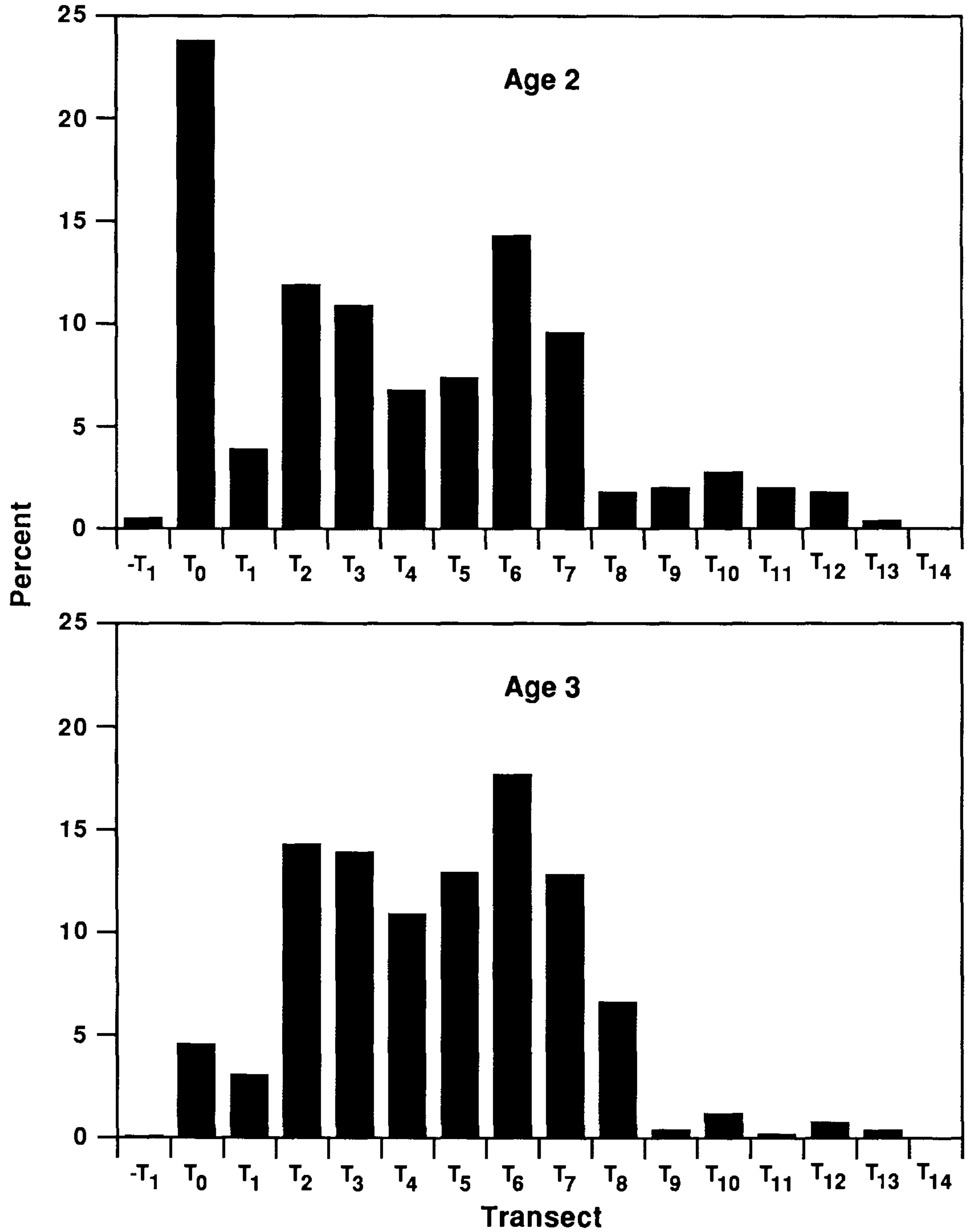

Figure 5.—Percent distribution of the catch per trawling hour of 2- and 3-year-old lake trout in the West Arm of Grand Traverse Bay in May of 1984-89.

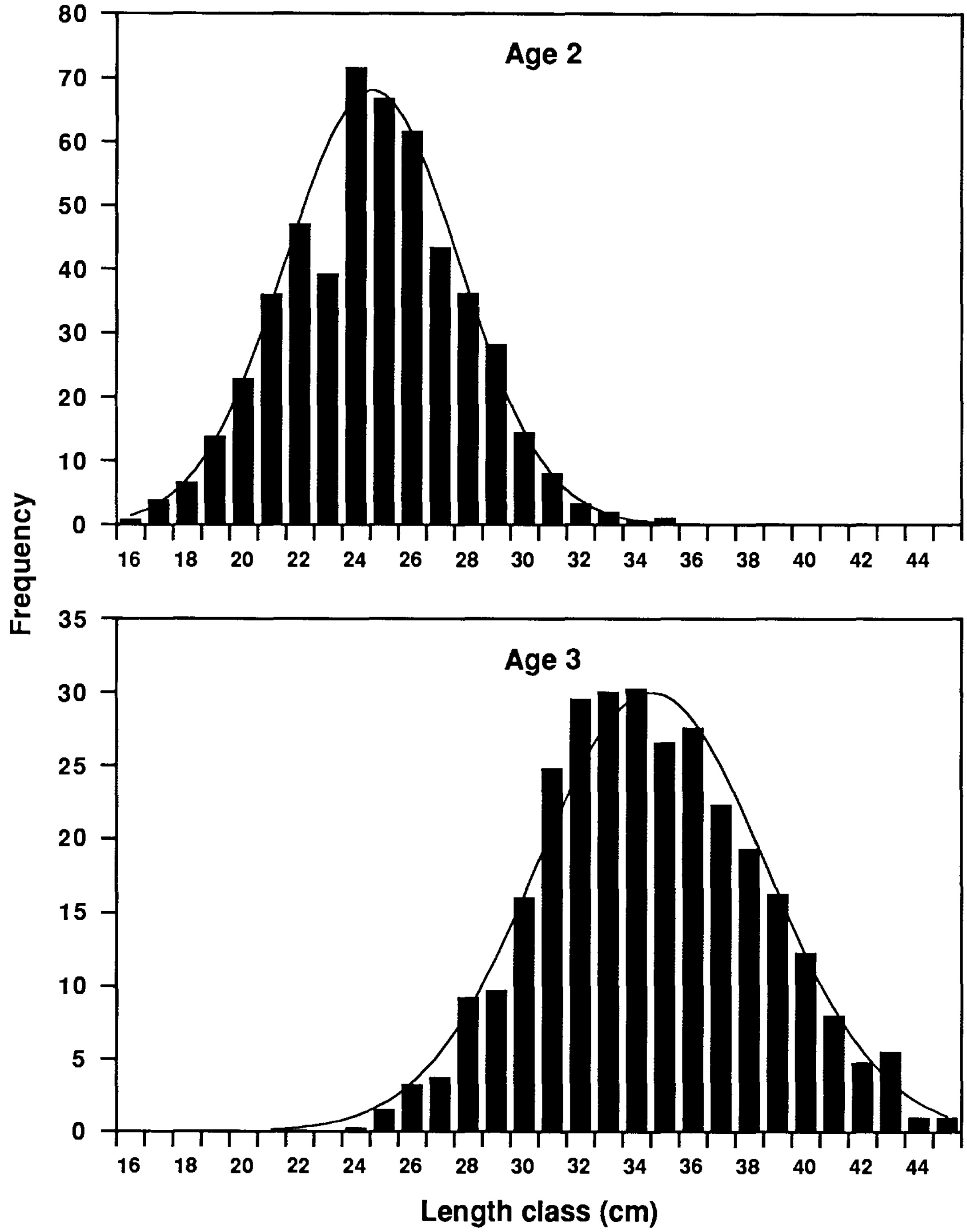

Figure 6.—Observed and normalized length frequencies of 2- and 3-year-old lake trout caught in survey trawls in the West Arm of Grand Traverse Bay in May of 1984-88. For the normalized length frequencies for 2-year-old lake trout, the mean = 25.1 cm and SD = 3.1 cm; for 3-year-old trout, the mean = 35.0 cm and SD = 4.1 cm.

Table 1.—Areas[1] under the catch curves of yearling lake trout during the 10-day period following stocking in the West Arm of Grand Traverse Bay, by day and year sampled.

	Year						
	1984[2]	1985		1986		1988	
Day	Area	Area	Percent	Area	Percent	Area	Percent
1	212.82	587.36	8.7	252.63	11.2	237.16	12.7
2	159.61	684.08	10.1	231.78	10.2	223.95	12.0
3	168.24	402.17	5.9	512.56	22.6	230.01	12.3
4	31.87	821.37	12.1	194.00	8.6	103.88	5.6
5	168.05	1,053.44	15.5	223.80	9.9	295.05	15.8
6	98.14	895.06	13.2	214.35	9.5	111.74	6.0
7	125.85	689.63	10.2	157.64	7.0	216.01	11.6
8	---	466.10	6.9	62.60	2.8	158.89	8.5
9	---	589.34	8.7	234.53	10.4	150.06	8.0
10	---	595.49	8.8	180.31	8.0	141.98	7.6
Total	---	6,784.05		2,264.20		1,868.87	
Mean	---	678.40		226.42		186.87	

[1]Based on trawl catch per hour, standardized for number stocked.

[2]Year designated as exploratory.

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