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Relative Survival of Lake Trout Stocked at Different Sizes and Quality in Lake Michigan

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ABSTRACT. *Beginning in 1995, the size of yearling lake trout* (Salvelinus namaycush) *stocked into the upper Great Lakes was increased based on the assumption that these fish would be healthier and survive better since natural mortality is thought to be inversely proportional to body size. We compared the post-release, relative survival of paired stockings of lake trout reared to 44 fish/kg (standard size) with larger fish reared to 22–26 fish/kg (enhanced size) in Lake Michigan. About 60,000 lake trout each of the standard and enhanced sizes for the 1994–1997 year classes were released as yearlings in spring near Clay Banks Reef, Wisconsin, and identified with coded-wire tags and an adipose fin-clip. Recaptures were made from 1997 to 2003 in four gill net surveys conducted in spring and fall near the release location. Comparisons of catch-per-unit of effort corrected for numbers stocked generally indicated no significant differences in relative survival of standard and enhanced lake trout. An autopsy-based assessment of overall fish health and condition indicated few measures where significantly different between standard and enhanced lake trout prior to stocking. Size differences between standard and enhanced fish remained statistically significant at all observed ages at recapture; however growth rates were the same for the two groups. Stocking numbers at certain sites on Lake Michigan were reduced concurrent with the change to larger yearlings with the expectation of increased survival, which did not occur; hence recruitment was essentially reduced in these areas for the restoration program.*

INDEX WORDS: *Lake trout, hatcheries, stocking, survival, size, Lake Michigan.*

INTRODUCTION

Maximizing the survival of stocked fish and the efficiency of hatchery facilities has been the focus of many studies in fisheries management. This has been the case as well for the lake trout (*Salvelinus namaycush*) restoration program in the Great Lakes. Post-release survival has been measured for a wide variety of variables that include stocking season (Buettner 1961, Pycha and King 1967, Elrod *et al.* 1988), size at stocking (Pycha and King 1967), strain stocked (Eshenroder *et al.* 1995, Elrod *et al.* 1995), method of rearing (Elrod *et al.* 1989), and method of stocking (Elrod *et al*. 1993, Elrod 1997). The centerpiece of the restoration program is the annual stocking of various strains developed from donor stocks (Krueger *et al.* 1983, Krueger and Ihssen 1995) that originated from the Great Lakes and adjacent waters. When stocking began in the early 1960s, a target size of about 44 fish/kg was

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adopted as the size standard (hereafter referred as "standard") for rearing yearling fish (14–16 months old) in federal and state hatcheries serving the upper Great Lakes. This was based on a comparison of the relative survival of fish reared at this and smaller sizes that were stocked and recovered in Lake Superior during the 1960s (Pycha and King 1967). At that time, the U.S. Fish and Wildlife Service's Pendill's Creek National Fish Hatchery (Brimley, Michigan) was the primary source of lake trout for the upper Great Lakes. Rearing conditions there could not produce yearlings larger than 44 fish/kg because of cold water temperatures during most of the year (annual average 6.9°C; range 0–21°C). In the 1960s and 1980s, construction of the Jordan River (Elmira, Michigan) and Iron River (Iron River, Wisconsin) National Fish Hatcheries, which had warmer, more thermally stable water, allowed for larger fish to be reared. Growing conditions were so much better at these hatcheries that fish were fed smaller rations or went unfed for long periods in spring before stocking to meet the standard size and not exceed the holding capacity of the raceways.

Beginning in 1995, the size of yearling lake trout stocked into the upper Great Lakes by the national fish hatcheries was increased to 22–26 fish/kg (hereafter referred to as "enhanced"). This change was based on the assumption that enhanced fish would be healthier, and survive better after stocking since natural mortality is generally thought to be inversely proportional to body size (see Lorenzen 2000). Further justification for enhanced lake trout was based on observed decreases in survival of standard lake trout stocked in other Great Lakes (Elrod *et al.*1993, Hansen *et al.* 1994, Cornelius *et al.* 1995), even though these declines were generally unrelated to size at stocking. Concerns about the health and quality of lake trout within national fish hatcheries also led to the change in size at stocking. Restoration needs for the upper Great Lakes demanded large numbers of fish from hatcheries that operated at maximum capacity. To meet this demand, rearing conditions often resulted in fish with low body fat, missing fins and eyes, and other manifestations of over-crowding. Regardless of these problems, stocking the standard fish resulted in rebuilding populations of lake trout that supported fisheries in all the Great Lakes (Cornelius *et al.* 1995, Elrod *et al.* 1995, Eshenroder *et al.* 1995, Holey *et al.* 1995) and lead to the restoration of lake trout populations in Lake Superior (Hansen *et al.* 1995, Bronte *et al*. 2003).

Rearing capacity of hatcheries is related to standing fish weight as opposed to numbers of fish, therefore any increases in fish size would result in less fish produced. It was assumed that increases in post-release survival of enhanced fish would offset decreases in the numbers of fish stocked. In 1994, the Lake Michigan Committee of the Great Lakes Fishery Commission approved the move to enhanced fish, and a plan to measure changes in survival (Lake Michigan Committee 1995). To measure the survival response, equal groups of standard and enhanced lake trout were stocked at Clay Banks Reef near Algoma, Wisconsin during 1995–1998. The objective of this study was to determine if enhanced lake trout survived better than standard lake trout in Lake Michigan. Evidence for increased survival would be demonstrated by significantly higher relative abundance of the enhanced fish compared to the standard fish in paired stockings of year classes measured in gill net surveys in later years. Similar measures of relative abundance between the groups would indicate that survival was not different.

METHODS

All lake trout used in this study were from the 1994–1997 year classes the Lewis Lake strain reared at the Jordan River National Fish Hatchery to avoid strain and hatchery effects when comparing the post-release survival of standard and enhanced fish. Eggs were fertilized from broodstock at the Saratoga National Fish Hatchery (Saratoga, Wyoming) in October and eyed eggs transported to Jordan River by December of each year to be reared for 14–15 months in water temperatures from 6.1–10.5°C. The eggs were incubated in hatching jars and hatched in late December. All fry were fed for optimum growth and reared indoors until late August and afterward, the fingerlings were moved to outdoor raceways and separated by study group. Fish were fed and held at densities to achieve the standard and enhanced quality and sizes, with exception of the 1994 year class when the size separation between the two groups was not as large as desired. The standard group was fed to achieve a growth rate that did not exceed 7.6 mm per month, and reach 49.6/kg at stocking. The enhanced group was fed to achieve growth of 10.1–15.2 mm per month and a size of 22.0–26.5/kg. Each group and year class received a unique coded-wire tag number and an adipose fin-clip to allow identification at recapture.

TABLE 1. Variables and conditions associated with the Goedes autopsy-based assessment of overall fish health and condition. P values are associated with either two-sample t-test or Chi square test for significant differences between standard and enhanced fish, all four year classes combined.

Feature	Units or metric	Normal Condition	Abnormal Condition	Mean, percent normal, or percent distribution		*P*
				Standard	Enhanced	
Total length (L)	mm			138	172	< 0.0001
Wet weight (W)	g			22	48	< 0.0001
Fulton's K	$(W*10^5)/L^3$			0.79	0.89	< 0.0001
Hematocrit volume	Percent of total			41.9	41.7	0.99
Leucocrit volume	Percent of total			0.899	0.875	0.92
Plasma protein volume	g/dL			5.1	5.7	< 0.0001
Blood glucose	mg/dL			67.9	71.1	0.63
Eyes	Percent normal	Clear, no aberrations	Swollen, bleeding, blind, missing, other	80	88	0.20
Gills	Percent normal		Frayed, clubbed, marginate, pale, other	91	100	0.006
Pseudobranchs	Percent normal	Flat or concave	Swollen, lithic, inflamed, other	90	83	0.16
Thymus	Percent normal	No hemorrhage	Mild or severe hemorrhage	95	89	0.15
Fins Right pectoral	Percent normal	No erosion	Missing (non clip) or degrees of erosion	53	89	< 0.0001
Left pectoral				96	91	0.19
Right pelvic				99	96	0.31
Left pelvic				100	96	0.08
Dorsal				83	79	0.55
Upper caudal				98	99	0.56
Lower caudal				99	99	1.00
Mesenteric fat	Fat around pyloric ceca	0 = no fat, 1 = 0-50% coverage, 2 = 50% coverage, 3 = 50–99% coverage, 4 = 100% coverage		0 = 21.3 1 = 47.5 2 = 25.0 3 = 5.0 4 = 0.0	0 = 0.0 1= 12.5 2 = 45.0 3 = 42.5 4 = 0.0	< 0.0001
Spleen	Percent normal coloration	Black, red, granular	Nodular, enlarged, other	96	100	0.08
Hindgut	Degree of inflammation	None	Mild, considerable inflammation of mucosa	100	100	1.00
Kidney	Percent normal coloration	Dark red	Swollen, gray, granular, urolithiasis, other	100	100	1.00
Liver	Percent normal coloration	Red or pale red	Tan, white nodules, discoloration, other	99	100	0.32

TABLE 2. Size at stocking and number stocked for each treatment group by year class, and number of lake trout caught by year class for each survey and year.

			Number of coded wire tagged lake trout caught by year class and treatment							
		Year Class	1994		1995		1996		1997	
		Treatment (fish/kg)	Standard (38.5)	Enhanced (31.7)	Standard (46.4)	Enhanced (25.3)	Standard (41.8)	Enhanced (24.2)	Standard (41.8)	Enhanced (21.3)
		Mean length (mm)	150	161	141	174	147	176	147	161
		No. stocked	60,000	63,000	60,700	60,800	61,100	60,300	55,800	59,100
Survey	Year	No. lifts								
Juvenile lake trout	1997	6	21	23	94	77	0	0	0	0
	1998	5	3	3	11	10	24	12	0	0
	1999	2	3	3	4	7	5	2	2	3
Lakewide assessment	1999	6	5	5	3	3	1	0	0	0
	2000	6	3	3	4	4	2	2	0	0
	2001	6	1	4	5	7	5	12	10	6
	2002	3	0	0	0	4	2	3	4	5
	2003	3	0	1	0	0	0	2	0	1
Juvenile lake whitefish	1997	6	25	33	0	0	0	0	0	0
	1998	5	13	18	2	2	0	0	0	0
	2000	6	1	0	1	4	3	10	10	17
	2001	4	0	0	0	0	2	0	9	20
	2002	4	0	0	1	0	0	2	5	2
	2003	3	0	0	0	0	0	0	0	1
Spawning lake trout										
	1999	5	12	9	3	0	0	0	0	0
	2000	4	3	1	0	2	1	0	0	0
	2001	8	8	14	5	1	1	2	1	3
	2002	5	12	19	13	11	8	5	7	2
	2003	8	8	4	7	2	1	1	4	4

We used an autopsy-based assessment of overall fish health and condition (Goede and Barton 1990, hereafter referred to as Goede's assessment) to quantify health and condition differences between standard and enhanced fish. This assessment involves a gross visual examination and ranking of the appearance and condition of external (eyes, gills including the opercle and pseudobranch, and fins) and internal (thymus, fat around pyloric ceca, color/condition of spleen, hindgut, kidney, liver, and bile) tissues and organs. Measures of length, weight, and condition are also collected. Rank classifications are based on deviations from normal conditions of the organs and tissues of healthy fish. This assessment is conducted on fish at national fish hatcheries during rearing and prior to stocking (Table 1); see Goede and Barton (1990) for specifics. To simplify our analysis, only the frequencies of normal and abnormal rankings were used as opposed to the analysis of degrees of abnormality indicated in the published procedure. We compared the results of this assessment between the standard and enhanced lots to determine if and where significant differences existed in the health/condition that may explain any observed differences in post-release survival. We used two-sample t-tests for continuous data and chi-square tests for categorical data to test for significant difference between standard and enhanced fish. Statistical significance was assumed at $\alpha \leq 0.05$.

About 60,000 fish of each treatment (standard and enhanced) of the 1994–1997 year classes were stocked into Lake Michigan near Clay Banks Reef between Sturgeon Bay and Algoma, Wisconsin in spring 1995–1998 when the fish where 14–15 months old (Table 2). Comparisons of the relative abundance of the treatment groups for each year class were made from recoveries of the coded-wire tagged fish in four gill net-surveys conducted within 80 km of the stocking site by the Wisconsin Department of Natural Resources and the U.S. Fish and Wildlife Service during 1997–2003. Eighty-two km is the approximate dispersion radius for most adult lake trout in that area (Schmalz *et al.* 2002) and 60 km for yearling fish recaptured as adults (Lake Michigan Lake Trout Task Group, Great Lakes Fishery Commission; unpublished data). The four surveys were as follows: 1) a juvenile lake trout survey in spring that fished 1,900–6,000 m gangs of 51 mm stretch-measure mesh gill nets near Clay Banks, 2) a juvenile lake whitefish (*Coregonus clupeaformis*) survey in spring that fished mostly 732 m gangs of 51-, 64-, 76-, and 89-mm stretch-measure mesh gill nets near Bailey's Harbor, WI, 3) a lakewide lake trout and burbot (*Lota lota*) survey in spring (Schneeberger *et al.* 1997) that fished 488 m gangs of 64–152 mm stretch-measure mesh gill nets by 25-mm increments near Sturgeon Bay, and 4) a spawning lake trout survey in fall that fished 244 m gangs of 114-, 127-, 140-, and 152-mm stretch-measure mesh gill nets at Clay Banks (Table 2). All nets were lifted after one night, weather permitting, and all coded wire tagged fish were sacrificed, and their snouts removed and frozen. At the lab, coded wire tags were extracted and decoded to determine year class and treatment affiliation.

Relative abundance (CPE) of fish caught from each treatment and year class was expressed as the average number caught per 305 m of net in each lift adjusted for the number of fish stocked to provide an index of survival where

$$CPE_j = \sum_{i=1}^{n} \left[(C_{j,i}/f)/S_j \right]/n,$$

C is the number of fish caught for year class j and gill net-lift i, f is the gill net-effort standardized to 305 m, S is the number stocked at age 1 for year class j and n is the number of gill net lifts. Relative abundance data were pooled across sample years for each treatment and compared for each survey because catches and number of lifts within a year and survey were low (Table 2). Treatment effects were also tested on CPEs pooled across year classes, years, and surveys. Because CPE data are not normally distributed, we used the non-parametric Wilcoxon Signed-Rank Test to investigate differences between the CPE of the standard and enhanced fish. Statistical significance was assumed at $\alpha \leq 0.05$.

We determined if growth differed between standard and enhanced fish after stocking. We compared estimates and asymptotic standard errors of $L_{oo,}$ (asymptotic length) and K (Brody growth coefficient) of the Von Bertalanffy growth equation fit to individual observed lengths at ages 2–7 for each group by combining all observations during 1997–2003. We used a non-linear least squares procedure with biologically reasonable seed values to estimate model coefficients. Similar estimates of K would indicate no growth difference between the groups (Francis 1996). We also compared lengths-at-age between standard and enhanced fish with ANOVA with length as the dependent variable to determine if length differences at stocking where maintained throughout life.

RESULTS

Few measures in the Goede's assessment were significantly different between standard and enhanced lake trout prior to stocking into Lake Michigan. As expected, enhanced fish where significantly ($P < 0.0001$) longer and heavier than standard fish, and had a slightly higher condition factor ($P < 0.0001$) (Table 1). Blood glucose levels were significantly ($P < 0.0001$) higher in enhanced fish as were the incidence of normal gills ($P = 0.006$), normal (non-eroded) right pectoral fins ($P < 0.0001$), and the amount of mesenteric fat ($P < 0.0001$).

We made 95 gill-net lifts that captured 769 lake trout that were from the paired stockings of standard and enhanced fish (Table 2). Of these, 378 fish were standard fish and 391 were enhanced fish. Comparisons of CPEs, corrected for numbers stocked, generally indicated no significant differences (all $P = 0.11$–1.00) in relative survival of standard and enhanced lake trout across all surveys, within individual surveys, or for year classes within a survey (Table 3). The exceptions were for the 1996 year class in the juvenile lake trout survey ($P = 0.04$), the 1995 year class in the lake trout spawning survey ($P = 0.02$), and all years aggregated in the lake trout spawning survey ($P = 0.02$). Results for these comparisons were contrary to expectations; CPE of standard fish was significantly higher than that of the enhanced fish. Distributions of CPE across lifts, indicated by standard deviations of the adjusted means, were similar and of the same magnitude for both standard and enhanced fish for most year classes in all the surveys.

TABLE 3. Comparison of the adjusted mean CPE of enhanced and standard fish by survey, year class, and years sampled.

Survey	Year Classes	Years Sampled	Enhanced fish	Standard fish	P-value
			Mean adjusted CPE (standard deviation)		
All surveys	1994–97	1997–2003	0.70 (1.38)	0.71 (1.43)	0.71
Juvenile lake trout	1994	1997–1999	0.54 (0.51)	0.51 (0.32)	1.00
	1995	1997–1999	1.85 (2.20)	1.96 (2.76)	0.60
	1996	1998–1999	0.64 (0.94)	1.31 (0.95)	0.04
	All	All	1.08 (1.58)	1.25 (1.87)	0.66
Lake wide assessment	1994	1999–2003	0.35 (0.49)	0.23 (0.58)	0.42
	1995	1999–2003	0.51 (0.76)	0.33 (0.55)	0.65
	1996	2000–2003	0.66 (1.03)	0.31 (0.48)	0.13
	1997	2001–2003	0.63 (0.97)	0.78 (1.28)	0.87
	All	All	0.51 (0.80)	0.37 (0.71)	0.16
Juvenile lake whitefish	1994	1997–2003	1.12 (1.34)	0.87 (1.21)	0.51
	1995	1998–2003	0.14 (0.24)	0.07 (0.21)	0.14
	1996	2000–2003	0.24 (0.51)	0.10 (0.24)	0.24
	1997	2000–2003	0.75 (1.40)	0.42 (0.77)	0.17
	All	All	0.57 (1.07)	0.37 (0.79)	0.11
Lake trout spawning survey	1994	1999–2003	1.84 (2.42)	1.77 (2.02)	0.38
	1995	1999–2003	0.66 (1.61)	1.15 (2.27)	0.02
	1996	1999–2003	0.33 (0.97)	0.45 (1.14)	0.78
	1997	1999–2003	0.38 (1.06)	0.54 (1.25)	0.26
	All	1999–2003	0.80 (1.72)	0.98 (1.80)	0.02

Growth rates were similar for both standard and enhanced fish as indicated by identical estimates of K (Table 4) and similar standard errors. Observed length-at-age, which was higher for enhanced fish at stocking (Table 2), remained significantly higher than standard fish at ages 2–7 years (F = 1385.9; df = 6, 635; P < 0.00001) (Fig.1). The calculated asymptotic length (L_{oo}) of the enhanced fish was higher than for standard fish.

TABLE 4. Von Bertalanffy growth function parameter estimates for standard and enhanced fish.

Parameter	Estimate	Asymptotic standard error	Wald 95% Confidence Interval
Standard fish (corrected R^2 = 0.93)			
L_{oo}	808	30	749–868
K	0.285	0.025	0.237–0.334
T_0	0.726	0.070	0.589–0.863
Enhanced fish (correct R^2 = 0.92)			
L_{oo}	835	29	778–891
K	0.285	0.024	0.239–0.332
T_0	0.736	0.073	0.592–0.881

DISCUSSION

Our results indicate that there was no significant difference in post-release survival of enhanced lake trout compared to standard lake trout at Clay Banks in Lake Michigan even though some measures of health and condition were significantly better for enhanced fish. The change to stocking enhanced fish in 1995 resulted in about 12% less total fish stocked and up to 40% less at a given stocking site compared to levels during 1985–1994, and led to a decrease in lake trout recruitment that was not offset by the anticipated increased survival. A substantial increase in survival of enhanced fish would be required to result in a significant increase in overall recruitment.

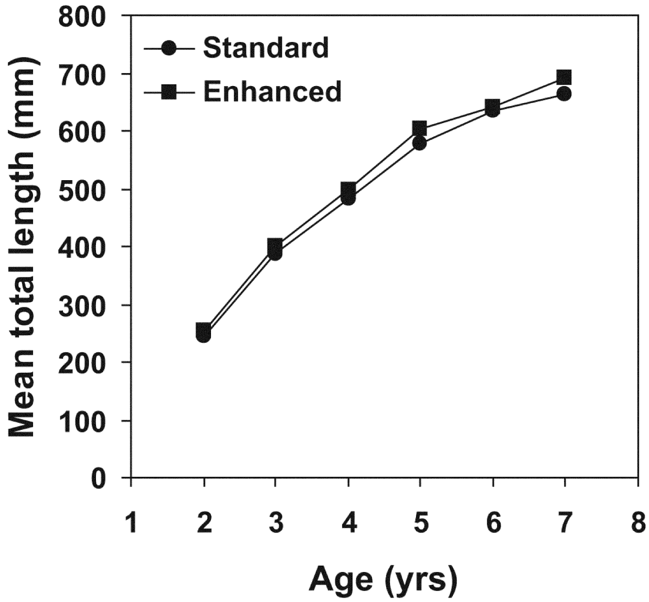

FIG. 1. Observed mean total lengths (mm) at age (yrs) for standard and enhanced fish recovered near Clays Bank, Lake Michigan.

These results represent survival results for only the Lewis Lake strain raised at Jordan River National Fish Hatchery and stocked in Lake Michigan. The lake trout restoration program utilizes many more strains from three separate production facilities and the outcome from stocking enhanced fish from these sources may not be similar. A similar, but more extensive study in Lake Huron of the performance of fish from the same strain, sizes, and production lots, indicated better post-release survival of the enhanced fish. However, the results varied by stocking location, year class, and year sampled (Aaron Woldt, U.S. Fish and Wildlife Service, 145 Water Street, Alpena, Michigan 49707, personal communication). Regardless, stocking enhance lake trout has been partially credited for increases in post-release survival in Lake Huron (Johnson *et al.* 2004). This may indicate a site effect not considered in the Lake Michigan experiment but given the inconsistent results from Lake Huron, and no significant differences reported here, suggests that any survival advantage of enhanced fish may be modest at best.

More extensive movement of the enhanced fish out of the study area could explain the lack of contrast in relative survival measured here but is unlikely. Recaptures of the experimental fish in a lake-wide, multi-agency survey of lake trout in Lake Michigan (Schneeburger *et al.* 1997) indicated that 11% of the standard fish and 12% of the enhanced fish were recaptured outside our primary study area and most where taken off Sheboygan, Wisconsin, about 100 km from the release location. This finding suggests that differential movements of the study groups did not influence our relative survival measures.

These results have led the U.S. Fish and Wildlife Service to reevaluate production and stocking targets in order to produce the most fish possible in their existing hatcheries. Current lake trout restoration plans for Lakes Huron (Ebener 1998) and Michigan (Lake Michigan Lake Trout Technical Committee 1985) call for a total of 10.6 million yearling lake trout to be stocked annually in U.S waters. Since capacities at national fish hatcheries cannot meet this demand, modified stocking targets have been adopted for both lakes that total 3.3 million fish annually for U.S. waters. In an attempt to address the production short comings, the national fish hatcheries have identified priority maintenance and construction projects necessary to improve existing capabilities and increase propagation. These projects include installation of liquid oxygen, upgrading surface water intakes, enclosing and replacing existing raceways, and adding new raceways. These improvements could increase production from about 3.6 million fish currently to 5.1 million fish without the construction of a new hatchery.

Future criteria for lake trout reared and stocked by national fish hatcheries will focus on fish quality rather than size (number/kg). Most Goedes measures were similar across standard and enhanced fish, and since relative survival did not differ between the groups, size was not relevant. Rearing lower densities of higher quality fish will also reduce stress and lower the chances of a disease epizootic. Since rearing environments are unique enough at each lake trout hatchery, fish-quality targets for characteristics such as visceral fat, and eyes, gills, and fin condition are being developed for each facility. These changes should increase the rearing capacity to help ensure the best post-release survival of lake trout stocked for restoration.

Changes in size at stocking should be pursued with caution. The decision to produce larger fish was made prior to the results of this study and the outcome showed no benefit to the lake trout restoration program in Lake Michigan. While stocking larger fish does appear to increase survival for many species (i.e., Dudash and Heidinger 1996, Szendrey and Wahl 1996), the case for lake trout is less clear. Most survival comparisons for lake trout in the Great Lakes have been between two life stages and clearly demonstrated that yearlings survived 2.4–9 times greater than much smaller fall fingerlings (Buettner 1961, Pycha and King 1967, Elrod *et al.* 1988). These comparisons, which likely influenced the decision to stock the enhanced fish, are not relevant here. Time of year, age at stocking, and larger differences at size at stocking are all potential effects that influenced survival, and those results are not directly transferable to the experiment described here.

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