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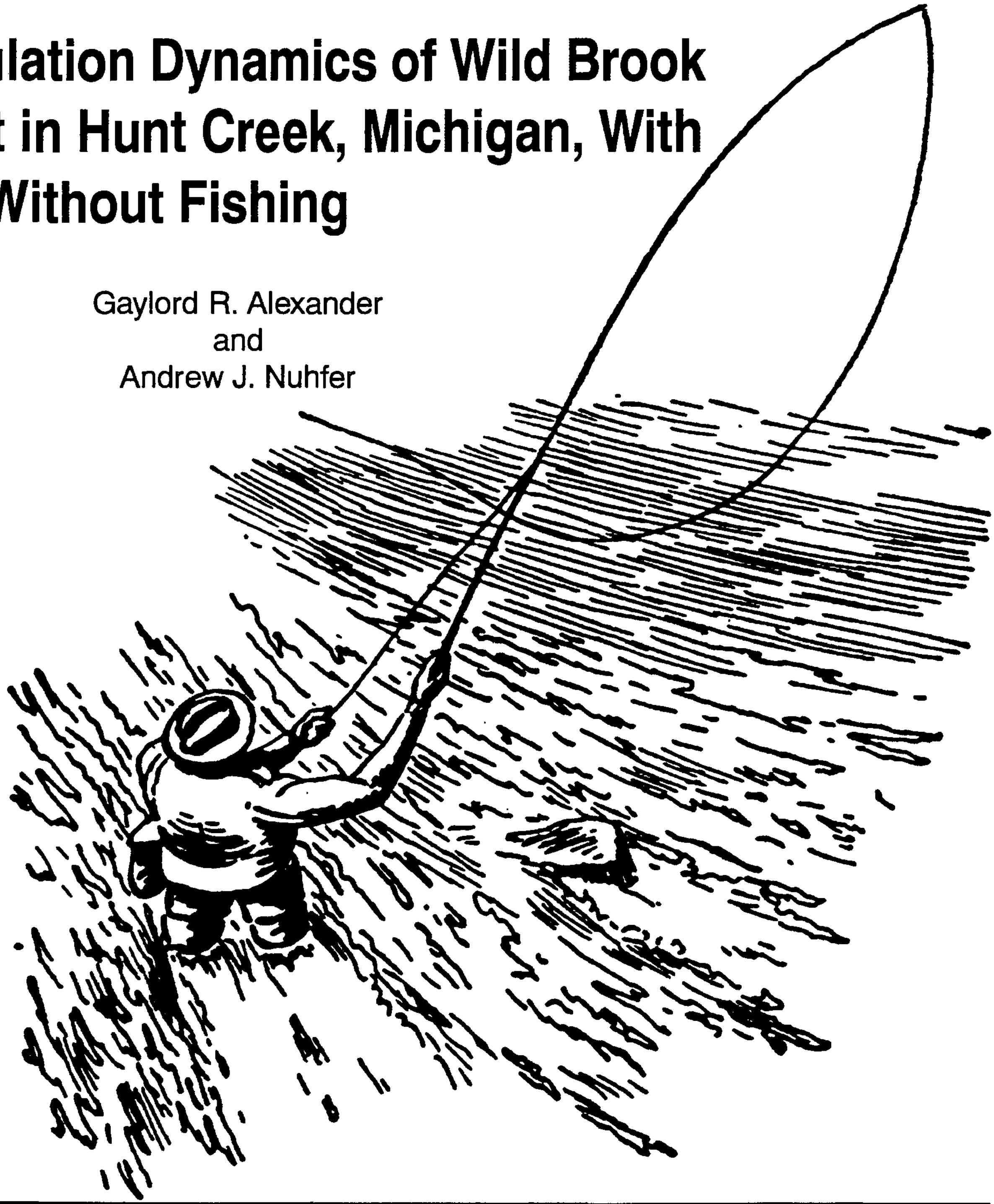

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Long Term Population Dynamics of Brook Trout in Hunt Creek, Michigan, With and Without Fishing

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Abstract.—We monitored the brook trout *Salvelinus fontinalis* population in a 2-mile section of Hunt Creek, Michigan, for 44 continuous years. In the first 17 years (1949-65), the population was subjected to fishing. In the last 27 years (1966-92) all fishing was prohibited. We conducted a complete creel census from 1949 through 1965 and trout abundance estimates every fall from 1949-92 and every spring from 1959-93. Our primary objective in this study was to compare brook trout population characteristics between periods of fishing and no fishing. Angler harvest of brook trout dramatically decreased the abundance and survival of legal-sized fish in Hunt Creek. Because fish were heavily cropped when they grew to a legal length survival of all age classes older than age 1 was significantly lower when the population was subject to fishing and harvest. Conversely, annual survival of trout from age 0 to age 1 was significantly higher during the harvest period. A complete creel census of trout catch during the fishing period showed that lower fall stock sizes and survival rates (spring to fall) observed were attributable to angler harvest. Fall brook trout populations of legal-sized fish were 127% higher when not cropped. However, about half of the increase in fall standing crop that was stockpiled by September during fishing closure was lost to natural mortality before the following April. Thus, the mean stock of legal-sized fish was only 65% higher by spring. Trout growth during 27 years when the stream was closed to fishing was not significantly slower than during 17 years with fishing in spite of an increase in total fall standing crop of about 25%. Only young-of-the-year trout in one stream section were found to be significantly smaller during the fishing closure. Populations of sublegal fish were not significantly affected by fishing and hence they reflected the range in natural variation that might be expected in a trout stream with a stable flow regime. During the 44-year study period the largest fall population of sublegal fish in the entire study area was 1.9 times the smallest population, while the highest spring population was 2.2 times higher than the lowest. The fall brook trout population in the least perturbed upper 1-mile of the study reach exhibited a significant increasing trend in abundance over the 44-year period. This suggested that environmental conditions may have improved for brook trout in Hunt Creek, and possibly other northern Michigan trout streams, over the past half century when development activities have been minimal. Conversely, fall populations of sublegal trout declined significantly over time in the lower 1-mile of the study reach where habitat quality was degraded by an experimental addition of sediment during 1971-76. This suggests that the adverse effects of bedload sediment have persisted in this stable-flow stream for approximately 20 years.

Our findings suggest that fishing regulations that reduce angling mortality of intensively-fished brook trout in small streams should significantly enhance populations of larger trout and improve the total catch of trout by anglers.

A portion of Hunt Creek in Montmorency County, Michigan, located within the boundaries of the Hunt Creek Fisheries Research Area, was closed to fishing in 1966 to protect the stream and its trout for research. This allowed research to be conducted without the confounding factor of fishing. This provided the opportunity to compare the biological characteristics and responses of a brook trout *Salvelinus fontinalis* population when harvested (1949-65) and not harvested (1966-93). Our 44-year data set also provided a rare opportunity to document brook trout population characteristics and natural variation over time in a stream with minimal anthropogenic disturbances. Because brook trout are easier to capture by anglers than other trout species such as brown trout *Salmo trutta* (Schuck 1941; Cooper 1951, 1952; Alexander and Peterson 1983) we expected that fishing closure would result in higher survival and standing crops of brook trout (Hunt 1970). We also hypothesized changes in trout density due to fishing closure would have little effect on trout growth rates. Although inverse density dependent growth has been observed for *Salvelinus* sp. in lakes (Langeland 1986; Donald and Alger 1989) previous studies of the brook trout in Hunt Creek have shown little effect of trout density on growth (McFadden et al. 1967; Alexander and Hansen 1983, 1988). A similar lack of density dependent growth in stream environments has been reported for brown trout and rainbow trout *Oncorhynchus mykiss* (Alexander and Hansen 1983; Elliott 1985a, 1988, 1989a).

The primary objective of this study was to describe and compare the dynamics of a brook trout population when harvested and when not harvested by anglers. A secondary objective was to describe variation and trends of the trout population over time.

Study Area

The 2-mile study section of Hunt Creek is a small trout stream with an average annual discharge of about 27 cfs at the downstream end and 7 cfs at the upstream end. It is located east of the village of Lewiston in the north-central Lower Peninsula of Michigan (T 29N, R 2E, Sections 25, 35, and 36) (Figure 1). Stream discharge increases very rapidly between the upstream and downstream boundaries due to flows from five tributary streams and significant groundwater inputs within the experimental reach. Stream discharge in Hunt Creek is extremely stable because precipitation falls on deep sand and gravel-glacial drift that yields little surface runoff but high groundwater recharge. The stable supply of cold ground water (47-49^{o}F) and moderate stream gradients of 5-25 ft/mile (Shetter 1968) are typical of headwater brook trout streams throughout much of northern Michigan. Moving sediment concentrations in Hunt Creek are less than the average found in most northern Michigan streams because there are few human developments and no agricultural activity upstream from the study reach. The experimental stream section of Hunt Creek was composed of two contiguous 1-mile sections (Figure 1). The upper section (BC) has a surface water area of 1.7 acres. The lower section (ZA) has a surface water area of 2.56 acres. The total study reach is referred to as BCZA in this report.

The fish community within the experimental reach is predominantly brook trout with moderate populations of mottled sculpins *Cottus bairdi* and slimy sculpins *Cottus cognatus*. A few white suckers *Catostomus commersoni*, creek chubs *Semotilus atromaculatus*, fathead minnows *Pimephales promelas*, northern redbelly dace *Phoxinus eos*, bluntnose minnows *Pimephalesnotatus*, hornyhead chubs *Nocomis biguttatus*, central mud minnows *Umbra limi*, brook sticklebacks *Culaea inconstans*, Iowa darters *Etheostoma exile*, and brown trout *Salmo trutta* are found occasionally. These uncommon species are primarily migrants out of lakes and ponds in the extreme headwaters of the watershed. A few hatchery-reared brook and rainbow trout were stocked into Hunt Creek from 1949-54. These small plants are not believed to have significantly altered the wild brook trout stock or the conclusions of this paper.

Methods

From 1949-92, population numbers, age, and growth were estimated for brook trout each September in both sections of Hunt Creek. From 1959-93, similar data were also collected each April. Section BC was open to fishing throughout the 1949-65 trout seasons under then prevailing statewide fishing rules. The minimum length limit was 7 in and creel limits were 15 trout during 1949-51 and 10 trout during 1952-65. Any type of natural bait or artificial lure could be used. The fishing season extended from the last Saturday in April through the Sunday following Labor Day from 1949-58. The season length was extended through 30 September from 1959-65. Section ZA was fished under the same fishing regulations as section BC except that during the fishing seasons of 1955-59 only artificial flies could be used (Shetter and Alexander 1962). Both ZA and BC were closed to fishing from 1966-93. When fishing was permitted in the Hunt Creek study section, all anglers were required to obtain a daily permit. At the end of each day's fishing, anglers were required to bring harvested fish to check stations where they were counted and other biological data were collected. Thus, virtually complete creel census records of harvest and effort were collected during the fishing period.

A study to measure the effect of experimental additions of sand sediment was initiated in section ZA in 1971. This experiment reduced total trout abundance (standing crop) in ZA primarily during the years 1973-82 (Alexander and Hansen 1986, 1988). Upstream section BC was used as a reference section for this experiment, and was not impacted by sand sediment. Therefore, trout abundance data for the years 1973-82 from section ZA were excluded from this analysis of fishing effects in ZA. Moreover, when data for sections BC and ZA were pooled, the years 1973-82 were excluded for both sections.

Comparisons of fall (September) trout population characteristics were made between periods when the population was fished and not fished. Similar comparisons were made for spring (April) trout population characteristics between the periods 1959-66 (fishing; spring estimates were initiated in 1959) and 1967-93 (no fishing). Although fishing was prohibited during the 1966 season, spring 1966 populations were placed in the fished group because they were presumably influenced by fishing done during 1965.

Trout population abundance was estimated in spring and fall using the modified Petersen mark-and-recapture method (Bailey 1951). Estimates were stratified by 1-in length groups. Trout were captured with direct-current electrofishing gear. Recapture collections were made two days after marking. With few exceptions, sampling was done during the third week of April and September each year. The entire 2-mile study section was electrofished during each sampling period. Representative samples of brook trout scales were used to apportion population estimates by length groups to estimates by age group. Scale samples were taken from 20-60 brook trout from each inch group in each section during every April and September sampling period. Standing crop estimates were determined by multiplying population estimates for an inch group times the mean weight of an individual brook trout in that inch group. Mean weights were obtained from the Hunt Creek brook trout length-weight relationship derived from samples taken during 1960-70.

Survival rates were displayed by plotting mean population estimates of age groups on a logarithmic scale for the fishing and no fishing periods. Percent survival of cohorts between sampling periods was determined by division of Bailey point population estimates. Confidence limits (95%) for survival estimates were computed and examined for overlap to determine significant differences in survival between fishing and no fishing periods. Because spring sampling did not begin until 1959, fall population data from 1949-58 were not included in the fishing period for semi-annual survival analyses. Mean length at age was determined following the procedure described by Alexander and Ryckman (1976).

Comparisons of population characteristics under conditions of fishing or no fishing were done by analysis of variance. Parameters compared were numbers and standing crops of trout in various size groups, numbers of trout of each age group, and mean lengths at age. The assumption of homogeneity of variance was tested using the Bartlett test (Neter and Wasserman 1974). Trend lines for populations were derived using least squares regression procedures. All statistical tests for this study were performed at the 95% significance level ($P = 0.05$). ANOVA and regression analyses were done using procedures in the SPSS/PC+ software package (Norusis 1988).

Results

Fall population changes

Sublegal fish—There was no significant change in the average number in fall or total standing crop of 2-3.9 inch trout between the fishing and no fishing periods (Figures 2 and 3). There was no significant change in the average number in fall or total standing crop of 4-6.9 inch trout in section BC (Figure 2). However, the mean number and standing crop of 4-6.9 inch trout in section ZA was significantly lower during the no fishing period by 17% and 18%, respectively (Figure 3). Mean numbers and standing crops for all sublegal-sized fish combined (2-6.9 inch fish) in BCZA were not significantly different between the fishing and no fishing periods.

Legal-sized fish—Fall abundance of brook trout larger than the legal size limit (7 inches) increased dramatically after Hunt Creek was closed to fishing. Both average number and standing crop of 7-9.9 inch trout increased significantly in both BC and ZA after fishing closure (Figures 2 and 3). Average number of trout of this size increased 135% in BC and 103% in ZA. Average standing crop in fall (weight) increased 155% and 124% in BC and ZA, respectively. The average number and standing crop of trout 10 inches or longer in the fall also increased significantly in both BC and ZA under no fishing (Figures 2 and 3). The average increase in numbers was 401% in BC and 435% in ZA. Average standing crops of trout 10 inches or longer increased 380% in BC and 420% in ZA.

Spring population changes

Sublegal fish—The average number and total standing crop of 2-3.9 inch brook trout in the spring population did not change significantly under no fishing in either BC or ZA (Figures 4 and 5). Significantly lower mean numbers and standing crops of 4-6.9 inch trout were present during April in BC when the population was not fished. However, no significant reduction of the mean number or standing crop of 4-6.9 inch trout was detected in section ZA (Figure 5). Similar to fall data, no significant change was found in either mean number or standing crop of total sublegal-sized fish (2-6.9 inches).

Legal-sized fish—The average total number and standing crop of 7-9.9 inch trout increased significantly for spring populations both in BC and ZA under no fishing (Figures 4 and 5). However, increases were smaller than those observed for fall populations. The increases in number of trout were 33% in BC and 82% in ZA. Increases in average spring standing crop were 48% in BC and 105% in ZA. Spring population numbers and standing crop of trout 10 inches and larger also increased significantly after fishing was prohibited (Figures 4 and 5). The percentage increases were very dramatic, with spring numbers of trout 10 inches or longer increasing 957% in BC and 1,387% in ZA. Standing crop of 10 trout ten inches or larger increased 858% in BC and 1,394% in ZA.

Survival

Fishing significantly reduced annual survival rates of brook trout and percent survival after age 1 (Figure 6). Conversely, survival of fish from age 0 to age 1 was significantly higher when trout were being harvested by anglers. During the fishing period the significant increase in mortality of brook trout first occurred at age 2 when most brook trout in Hunt Creek attained the 7-inch minimum length for angler harvest. After fishing closure, mean annual survival from age 1-2 rose from 14 percent to 33 percent. Annual survival from age 2-3 increased from 12 percent to 18 percent, and survival from age 3-4 increased from 2 percent to 16 percent after angler harvest ceased. Virtually all age-3 and -4 brook trout were larger than the minimum length limit for angler harvest and annual mortality was significantly higher for fish of these ages during the fishing period. During the fishing period no age-5 trout survived to the September sampling period, but after harvest ceased 8 percent of fall age-4 fish survived to age 5.

Mean overwinter survival of age-0 brook trout fell from 49 to 40 percent after angler harvest ceased (Table 3). However, estimates of mean overwinter survival for age-0 brook trout were not significantly different between fishing and no-fishing periods. Regression analysis showed a significant inverse relationship between fall densities of age-0 trout and overwinter survival, but the fit was poor (R^2 = 0.23). When September densities of age-0 trout were between 2,000 and 3,000 fish/mi there was no significant relationship with overwinter survival. A significant, but weak (R^2 = 0.18) negative relationship between fall density of age-1 trout and overwinter survival was also observed. However, this regression relationship was strongly affected by high survival during rare years when fall densities of age-1 fish were less than 850 fish/mi. When these years were omitted from analysis there was no apparent relationship between survival and fall trout densities at age 1. Overwinter survival from age 2 to 3 was 15 percent higher (81%) when the population was being harvested. This observation of higher mean overwinter survival for age-2 fish during the harvest period (when fall age-2 fish were only about half as abundant) was not obviously related to density effects because the regression relationship between fall density and survival for individual years was not significant. Similarly, although mean overwinter survival from age 3 to 4 was nearly 17 percent higher (78%) during the harvest period, when fall abundance of age-3 brook trout was 3.3 times lower than their no-harvest level, there was no significant regression relationship between density and overwinter survival. The estimate of mean survival from age 4 to 5 for the harvest period was not reliable because age-5 fish were rarely found, but during the period that harvest was prohibited mean overwinter survival was 58 percent.

Brook trout of ages 2 through 4 had much lower survival rates from spring to fall during the period when they were harvested (Table 3). After harvest was banned, mean spring to fall survival of age-2 fish rose from 23 to 57 percent. Similarly, survival of age-3 fish nearly doubled from 18 to 33 percent. Survival of age-4 fish after angler harvest ceased (27%) was 3 times higher than during the harvest period. Age-1 fish, which were too small to be legally harvested, exhibited only a minor reduction in survival (6%) after harvest was banned. The estimates for survival of age-1 fish between spring and fall are inflated by immigration of age-1 brook trout from tributaries (Figure 1) into the study sections.

Angler harvest

Our data indicated that angler harvest was responsible for the lower populations of legal-sized trout in the fall when the population was fished. In both sections BC and ZA, the sum of mean harvest plus fall populations of fish 7 inches or longer during the fishing period were significantly higher than the mean populations of fish of this size after fishing closure (Table 1). In the combined sections, an average of 157 more legal-sized fish were produced per year when the stock was harvested. It appeared that relatively more of the production of larger fish was lost to natural mortality when the creek was closed to fishing.

Growth

Mean length at age—A statistically significantly reduction in fall length at age was found only for age-0 trout in section BC after fishing closure (Table 2). Estimates of mean length at age for age-1 and age-3 fish decreased slightly after the brook trout population was not fished. Mean lengths of age-2 fish were slightly (but insignificantly) higher after fishing closure. However, these fall length estimates for the harvest period were biased downward because substantial portions of the larger or faster-growing members of harvested age-2 cohorts were removed by anglers before fall sampling was conducted. Comparisons of mean length at age for age-4 or older fish between the fishing and no fishing periods were unreliable (and in some cases not possible) because so few fish lived to age 4 during the fishing period.

Length frequency—Angler harvest of trout resulted in dramatically lower numbers of fish measuring from 7-13.9 inches during the fishing period. This reduction was evident in both sections BC and ZA (Figure 7) The numbers of 4-6.9 inch trout were nearly the same irrespective of harvest. However, the mean number of 2-2.9 inch trout increased whereas the 3-3.9 inch trout decreased when the population was not harvested due to a slight decrease in fingerling growth rates. Finally, even though significantly greater numbers of 7-13.9 inch trout were present when the population was not fished, brook trout longer than 13.9 inches were not produced in Hunt Creek at any time during the 44-year study period.

Population variation between years-Sublegal fish

In general, variation in population size of sublegal-sized fish did not appear to be altered much by angling harvest. Fall populations of 2-3.9 inch fish in both BC and ZA were slightly more variable during the fishing period while 4-6.9 inch fish numbers were slightly less variable. Figures 2 through 5 illustrate that populations varied considerably from year to year. Over 44 years the highest fall population of all sublegal fish (2-6.9 inches long) in BCZA exceeded the lowest population by a factor of about 1.9 (maximum/minimum = 1.9). During the harvest period the number of 2-6.9 inch fish in BCZA varied by a factor of 1.7. During fishing closure numbers varied by a factor of 1.6. During the 44-year study period fall populations of 2-3.9 inch and 4-6.9 inch trout in section BC and 4-6.9 inch trout in ZA each varied by a factor of about 2.5. In ZA the fall population of 2-3.9 inch trout was more variable (factor of 3.3).

Populations of all sublegal-sized trout in spring were more variable than in fall over the study period. In BC, spring numbers of sublegal-sized trout were much more variable during the no fishing period, but in ZA there was essentially no difference in variability between the fishing and no fishing periods. Over 44 years, the highest spring population of all sublegal fish in BCZA exceeded the lowest population by a factor of about 2.2. During the fishing period, spring abundance in BCZA varied by a factor of 1.7 and during the no fishing period by a factor of 2.2. During the 44-year study, BC abundance of 2-3.9 inch and 4-6.9 inch trout each varied by a factor of 5.3. In ZA 2-39 inch and 4-6.9 inch trout abundance varied by factors of 4.4 and 3.1, respectively.

Long-term population trends-Sublegal fish

Spring and fall populations of sublegal-sized brook trout displayed no significant long-term trend in the 2-mile study section during the past 44 years (Figure 8). Populations increased significantly over time in BC during the fall, but not in the spring. In ZA, fall populations declined significantly over time, while the spring populations of sublegal fish showed no significant trend. The fall downward trend in section ZA could be due to the residual effect of sand bedload added to ZA during 1971-76 (Alexander and Hansen 1986, 1988).

Discussion

Survival

Data from the complete creel census strongly suggested that angler harvest was the primary cause of reduced survival and dramatically reduced populations of older fish during the fishing period, particularly during fall. After angler harvest ceased, higher survival caused a statistically significant increase in mean fall standing stock of legal-sized brook trout of about 130%.

Knowledge of potential population increases is very useful for projecting benefits from fishing regulations designed to increase angler catch of trout and quality of fishing. Our findings indicated that catch-and-release regulations or a minimum size limit of 12 inches could nearly triple numbers of legal-sized brook trout in headwater brook trout streams, assuming hooking mortality was insignificant. After a fishing-closure refuge was established on a section of Lawrence Creek Wisconsin, Hunt (1970) determined that angling had been the primary factor limiting the density of trout in the refuge. Increases in trout populations that might be expected from harvest restriction regulations or fishing closure will be greater when the percentage of trout harvested is higher. Thus, more catchable trout species such as brook or rainbow trout are more likely than brown trout to develop higher standing stocks in response to harvest restrictions. For example, Anderson and Nehring (1984) reported dramatic increases in standing stocks of rainbow trout in the South Platte River in Colorado after catch-and-release regulations were imposed. By contrast, 8 years of fishing closure on a section of Gamble Creek Michigan did not increase the density of legal-length fish in this brown trout population that was lightly exploited prior to closure (Gowing 1975).

Our findings also may not apply to larger streams with more diverse fish communities. A field test of catch-and-release regulations applied to a portion of the South Branch of the Au Sable River did not result in a significant increase in brook trout populations or angler catch rates (Clark and Alexander 1992). Perhaps brook trout in the South Branch of the Au Sable River did not increase significantly because they were not as abundant as in Hunt Creek. In the South Branch of the Au Sable, brook trout 7 inches or longer average 10 fish per acre compared to over 150 per acre in Hunt Creek. Further, brook trout coexist with an abundant brown trout population in the Au Sable River. Interspecific competition and predation by brown trout in the Au Sable River may have limited the brook trout population more than angling. Less probable reasons for differences in responses of Hunt Creek and South Branch populations are poaching and hooking mortality of caught-and-released brook trout. Gigliotti (1989) reported excellent compliance with catch-and-release regulations on the Au Sable River. Regulations on the Au Sable River also required the use of artificial flies. Several reviews of hooking mortality studies indicate that mortality of brook and brown trout caught on such tackle is probably less than 5% (Wydoski 1977, Mongillo 1984).

Even though the adult brook trout population increased dramatically after Hunt Creek was closed to fishing, only minor changes occurred in the populations of sublegal fish. Changes in egg or fry survival, or emigration of fry, apparently took place after Hunt Creek was closed to fishing, because there was no change in the mean fall populations of young-of-the-year trout even though more eggs were available and presumably spawned. Because young-of-the-year trout are too small to capture with our gear during April sampling periods, we could not determine if hatching success changed after fishing closure. McFadden et al. (1967) estimated egg complements of mature female brook trout in Hunt Creek from 1949-62 and reported that larger egg complements tended to experience lower survival to fall fingerling size. Inverse density-dependent survival of young brown trout in streams during their first spring and summer of life has been well documented (Elliott 1984, 1985b, 1989b). There was a weak ($r^2 = 0.23$) inverse relationship between density and overwinter survival of age-0 brook trout in Hunt Creek. Overwinter survival was probably density independent during years when densities of fall age-0 brook trout ranged from 1,250-

1,875/km (during most years of observation densities fell within this range). Hunt (1969) made the remarkably similar observation that overwinter survival of brook trout in Lawrence Creek appeared to be independent of September fingerling densities particularly when densities were less than 2,200/km. He noted further that during most winters larger fingerling body size and warmer water temperatures influenced survival more than stock densities. Larger mean lengths of fingerling in the upstream half of the Hunt Creek study area were weakly associated with better overwinter survival ($r^2 = 0.18$, $P = 0.01$) but in the downstream half of the study section the observed positive relationship ($r^2 = 0.12$) was not statistically significant ($P = 0.09$).

Even though fall stocks of legal trout increased 127% after fishing closure, about half of this increase was lost to over-winter mortality, resulting in spring stocks being only 65% larger. Although these greater over-winter losses during the no fishing period suggested that survival of older fish in Hunt Creek decreased as density increased, we believe that temporal factors unrelated to fishing reduced survival. We reached this conclusion because almost all regression relationships between fall densities of age-1 and older fish and overwinter survival were not statistically significant. Residual effects of manipulation of sediment loads in the downstream half of the study area were a likely cause of temporal changes in survival. Our analysis of fishing effects excluded population data for the years 1973-82 for stream reach ZA because stream morphology and trout standing crops were most obviously impacted during that period (Alexander and Hansen 1988), but perhaps we should have excluded data for a longer time period.

Growth

In general, growth rates and average size at age did not change during the study due to fishing closure. We found a significant decrease only for age-0 trout in section BC. This may reflect more intense competition for food or space either with the greater number and standing crop of older trout present or with the possibly greater numbers of juveniles hatched (but not surviving to fall).

The maximum size of trout (just under 14 in long) observed over 44 years in Hunt Creek did not change when angler harvest ceased, even though more trout lived to older ages. The incremental gain in growth by the oldest fish remained very slight. We believe food resources and energy demands in Hunt Creek limited the maximum size attainable in this habitat. Hunt (1991) reached a similar conclusion after evaluating results from a study of a brown trout fishery protected by regulations requiring release of small and large trout but allowing harvest of intermediate-sized trout. Bachman (1982, 1984) reported that the ultimate length of drift feeding brown trout in stream habitats was asymptotic, and proposed that trout in streams tend to grow only to a size at which energy captured from the drift equals energy expended to capture food and reproduce. Some large brown trout in Michigan's Au Sable River system appear to escape this energetic bottleneck by adopting active-search feeding strategies, presumably to increase consumption of large food items such as fish (Clapp 1988; Hudson 1993). However, brook trout in Hunt Creek and Lawrence Creek appear to be quite sedentary (Shetter 1968, Hunt 1970) and hence are presumably more dependent upon limited energy available from drift.

Long-term population variation and trends

Population variation of sublegal-sized fish appeared to be driven primarily by natural causes, because differences in the magnitude of variation between fishing and no fishing periods were minor. One exception was the large difference in variability of spring populations between fishing and no fishing periods in section BC. Since spring population data for the fishing period spanned only 8 years compared to 27 years for the no fishing period, there was a higher probability of more extreme variation in natural conditions during the latter period. Similarly, the lower variability observed in ZA and both sections combined may have been due partly to the reduced time period since some years were deleted from analysis because of experimental manipulation of sediment loads.

Differences in between-section trends in numbers of sublegal-sized fish during 44 years may be linked to anthropogenic disturbances other than fishing. Brook trout stocks in the upstream segment (BC), which was less perturbed, exhibited a significant increasing trend in numbers of sublegal and total trout. This suggests that environmental conditions may have improved for brook trout in Hunt Creek (and possibly other northern Michigan trout streams) during the past half century when development activities have been minimal. Timber has been harvested within the watershed (but not within the stream corridor) during the study period, and increased traffic on the road crossing of section BC probably has caused a slight increase in sand sediment delivered to the stream. Fall populations of sublegal trout declined over time in the downstream mile (ZA), where habitat quality was degraded by experimental additions of sediment during 1971-76. Adverse effects of bedload sediment documented by Alexander and Hansen (1986, 1988) may have persisted in this stable stream for approximately 20 years.

Implications

More restrictive fishing regulations that reduce cropping and hooking mortality of brook trout in intensively fished small streams should significantly enhance populations of larger trout and total catch of trout by anglers. However, this generalization may not apply to all streams, and mortality during the winter may limit the number of fish that can be stockpiled for anglers, even in high quality streams like Hunt Creek. Dramatic increases in populations of older trout in response to restrictive harvest regulations are most likely to be seen in brook or rainbow trout populations, which are more vulnerable to angler harvest than brown trout. Growth did not decrease significantly for adult trout in this study, even though total trout standing crop was considerably higher after harvest ceased. Thus, there is probably little danger of significantly reducing growth rates following adoption of restrictive regulations that increase standing crops of brook trout.

Trout populations increased significantly from 1949-93 in the section of Hunt Creek where there has been minimal development. This suggests that there has been no long-term degradation of habitat conditions due to trends in climate or chemical contamination levels (atmospheric deposition of acid and other toxic chemicals). However, numbers of trout less than 7 in declined over time in the lower section because it was degraded experimentally with sediment. Degradation occurred for only about 5 years, but the brook trout population apparently has not fully recovered nearly 20 years later.

The shorter term trends apparent within our data set also illustrate the potential danger of making inferences about effects of management activities based upon data spanning only a few years. To minimize this danger, managers and researchers should strive to design population studies that span at least one generation of fish and should also estimate populations in unmanaged reference sections. This will reduce the probability of attributing natural temporal population changes to management activities.

Acknowledgments

We thank the many employees of Department of Natural Resources and the U.S.D.A. Forest service who have helped collect data for this study over the past 44 years. We also thank the students of Michigan State University and the University of Michigan who likewise assisted on population surveys.

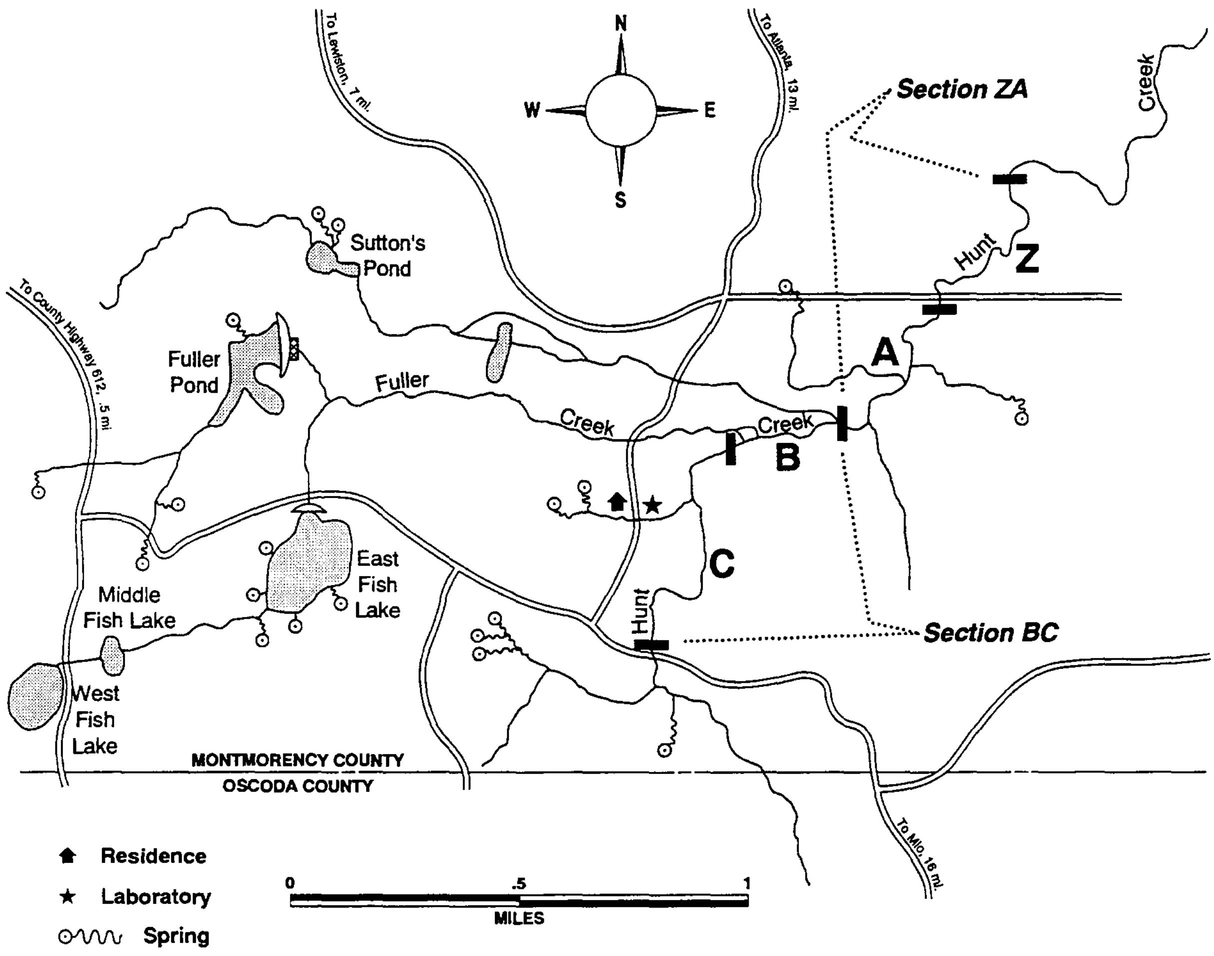


Figure 1.—Map of upper Hunt Creek, Michigan, showing the study sections, major tributaries, and geographic location.

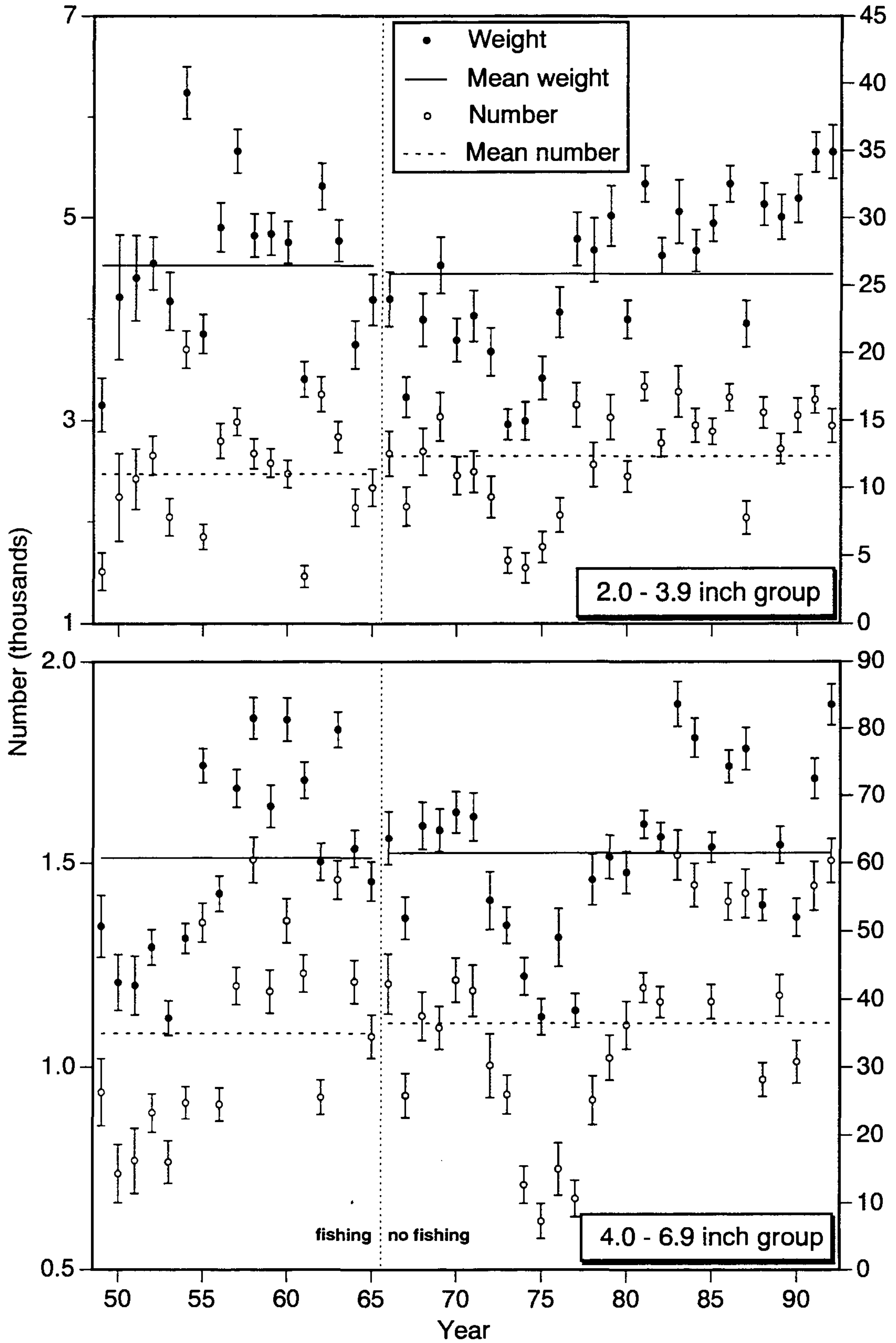
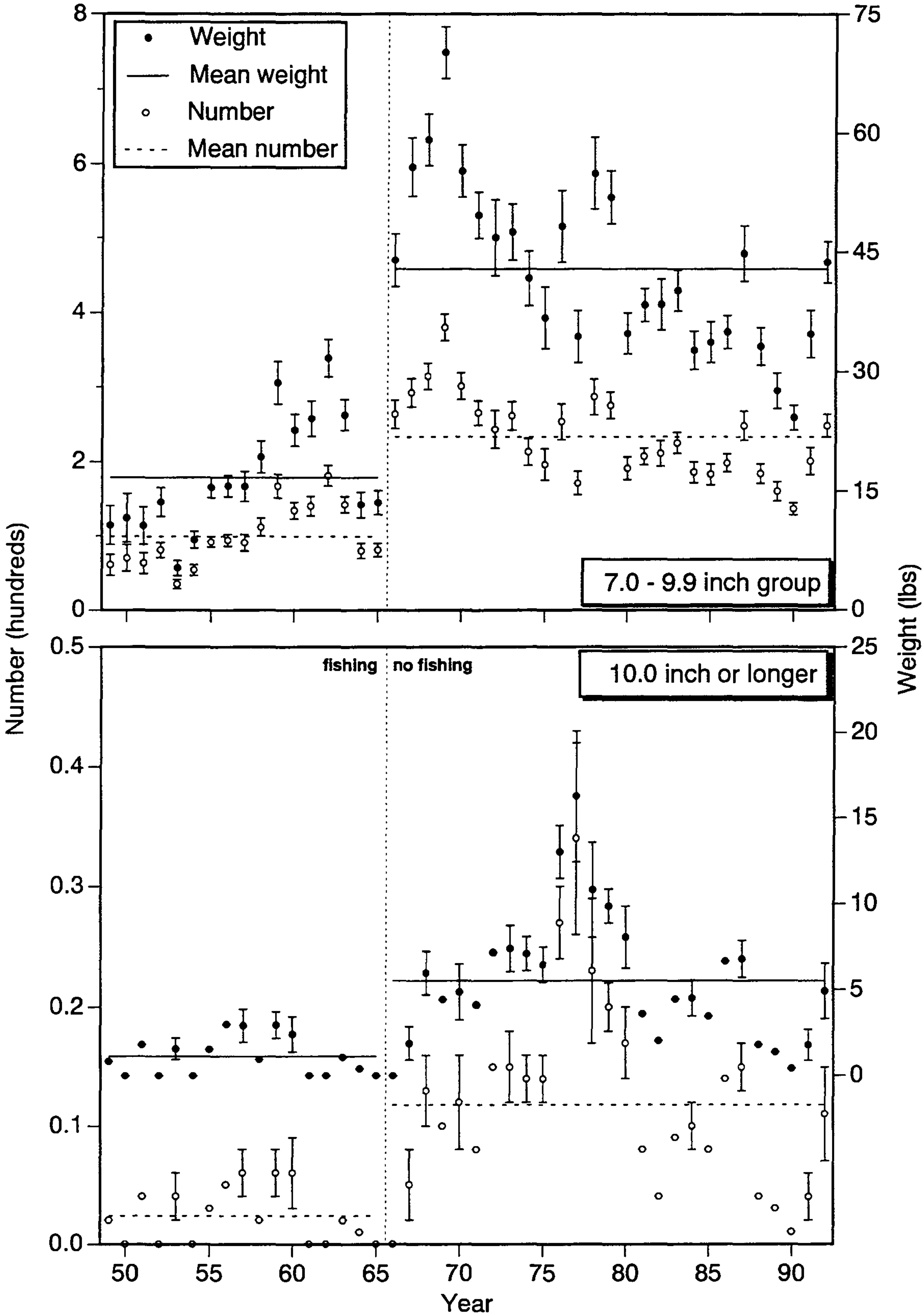


Figure 2.—Fall numbers and standing crops (pounds) of brook trout of various sizes in section BC of Hunt Creek, 1949-92. Means for the fishing (1949-65) and no fishing (1966-92) periods are shown by horizontal lines. Errors bars represent 2 standard errors.



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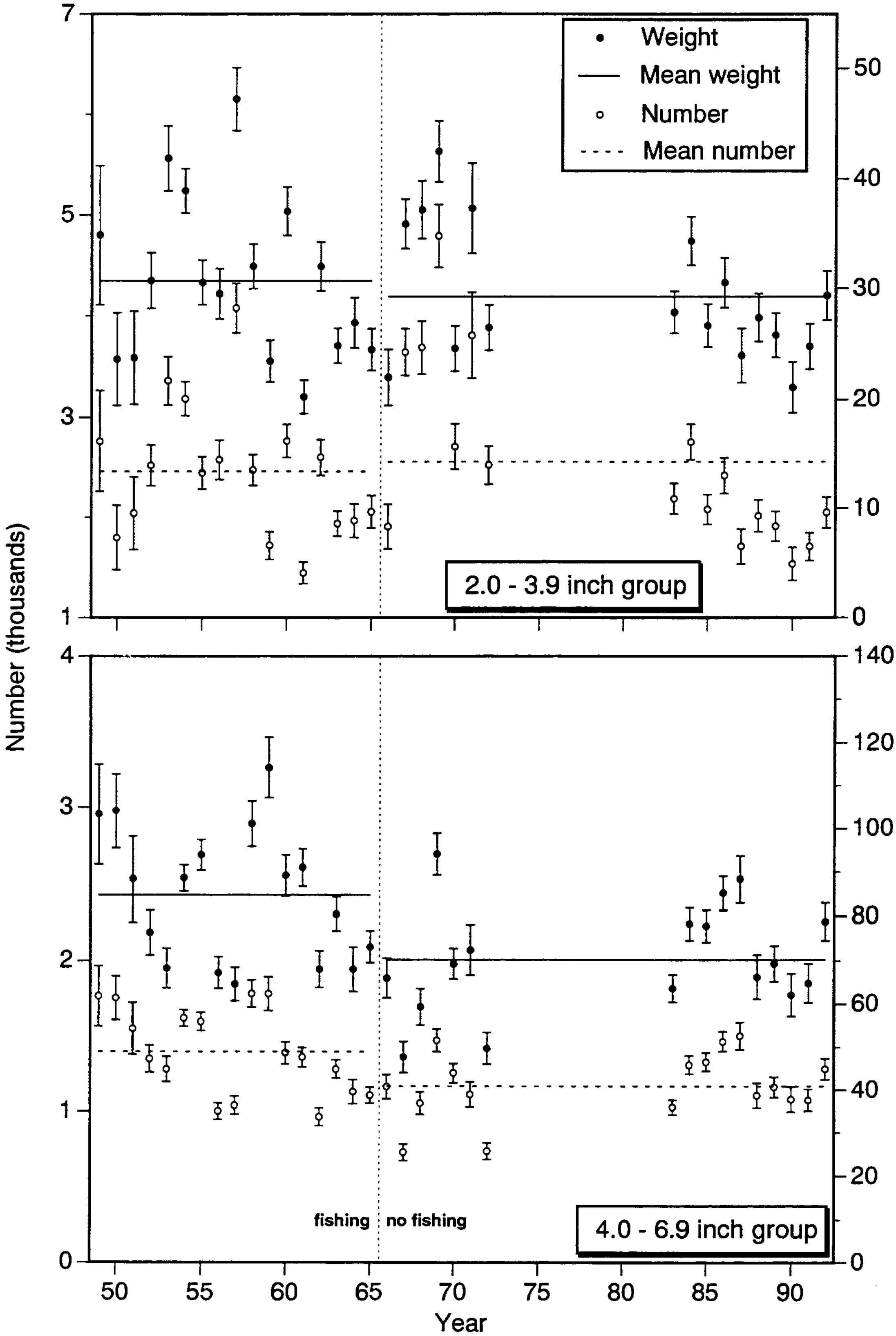

Figure 3.—Fall numbers and standing crops (pounds) of brook trout of various sizes in section ZA of Hunt Creek, 1949-92. Means for the fishing (1949-65) and no fishing (1966-92) periods are shown by horizontal lines. Errors bars represent 2 standard errors.

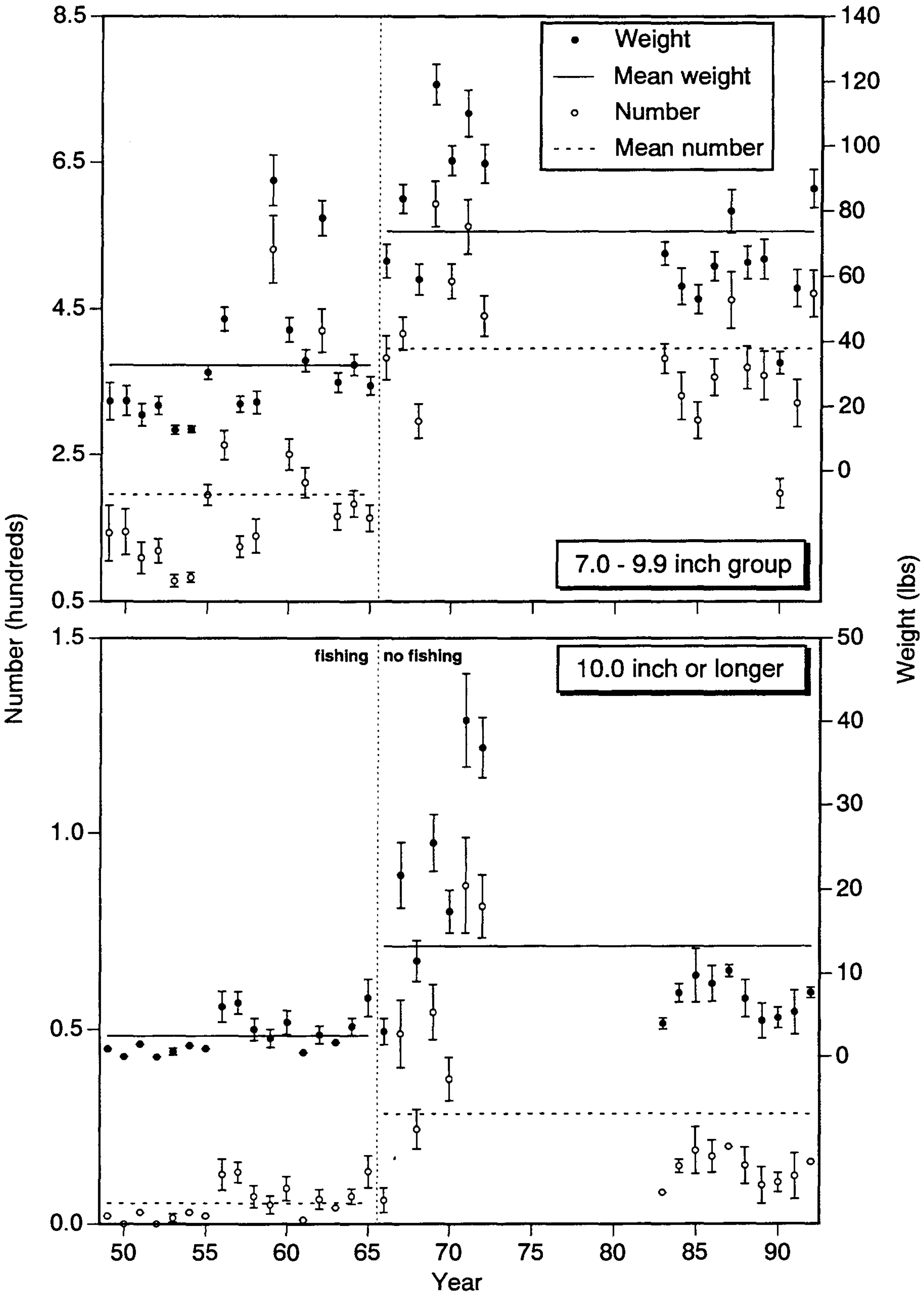

Figure 3.—Continued.

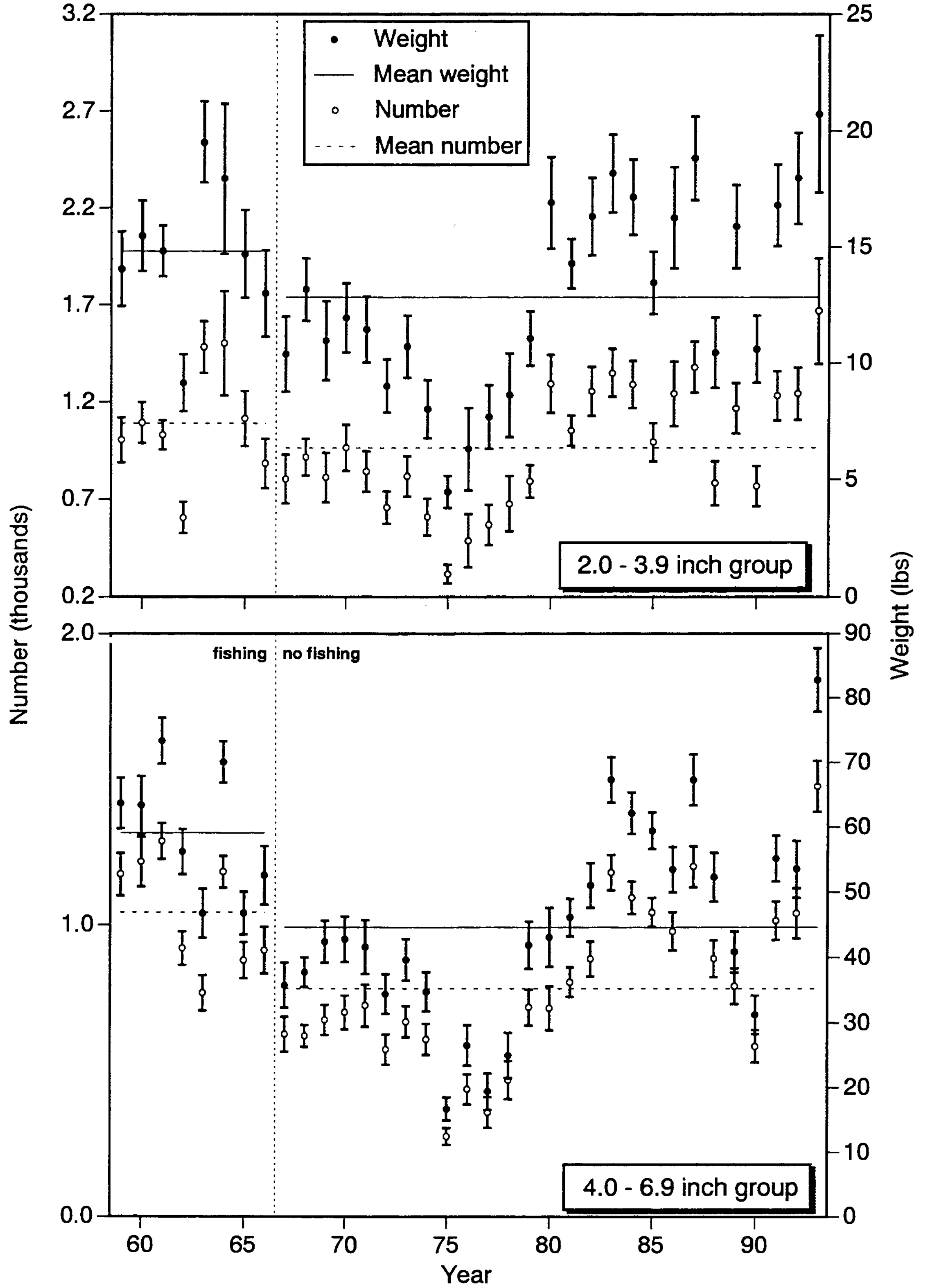

Figure 4.—Spring numbers and standing crops (pounds) of brook trout of various sizes in section BC of Hunt Creek, 1959-93. Means for the fishing (1959-66) and no fishing (1967-93) periods are shown by horizontal lines. Errors bars represent 2 standard errors.

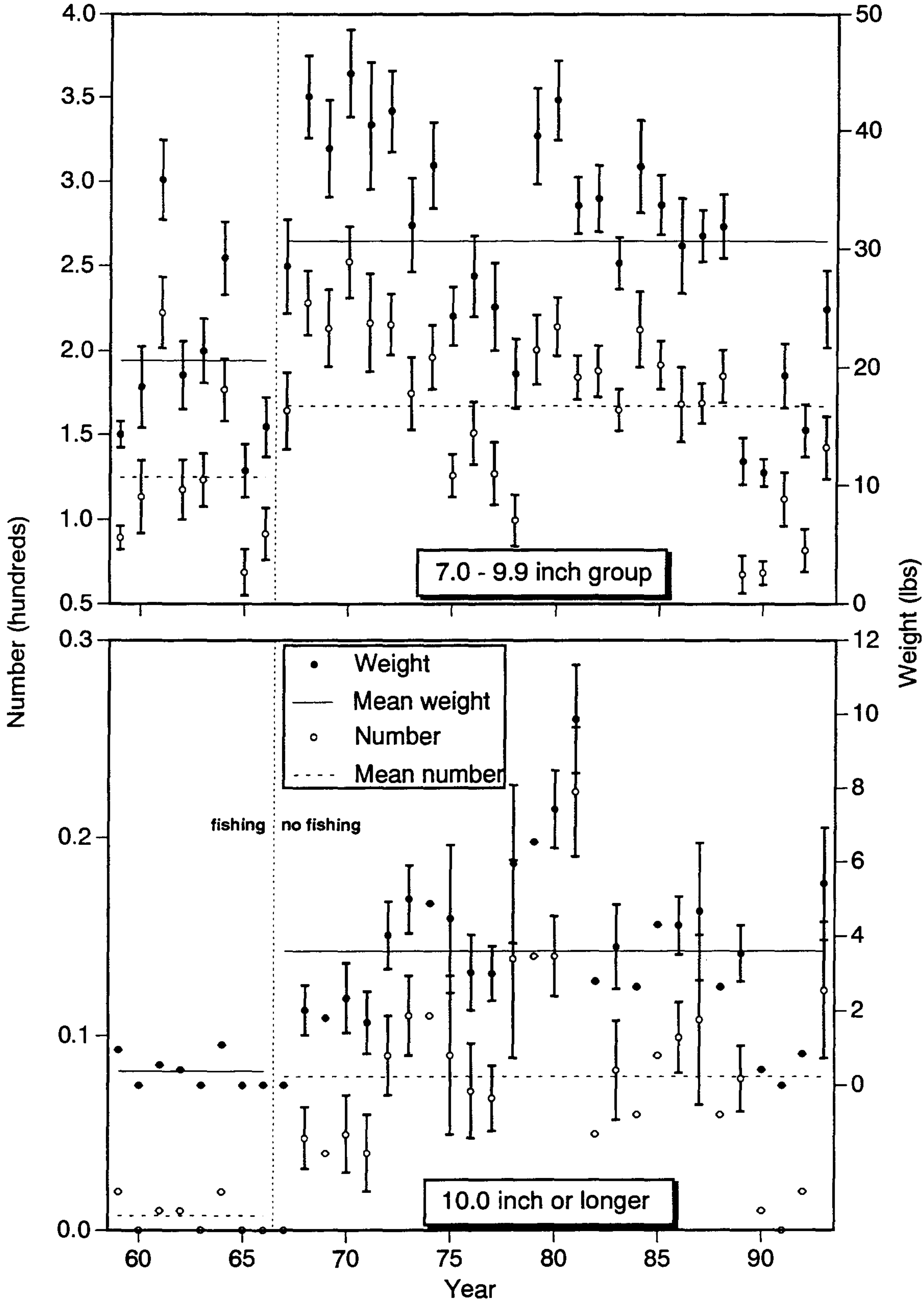

Figure 4.—Continued.

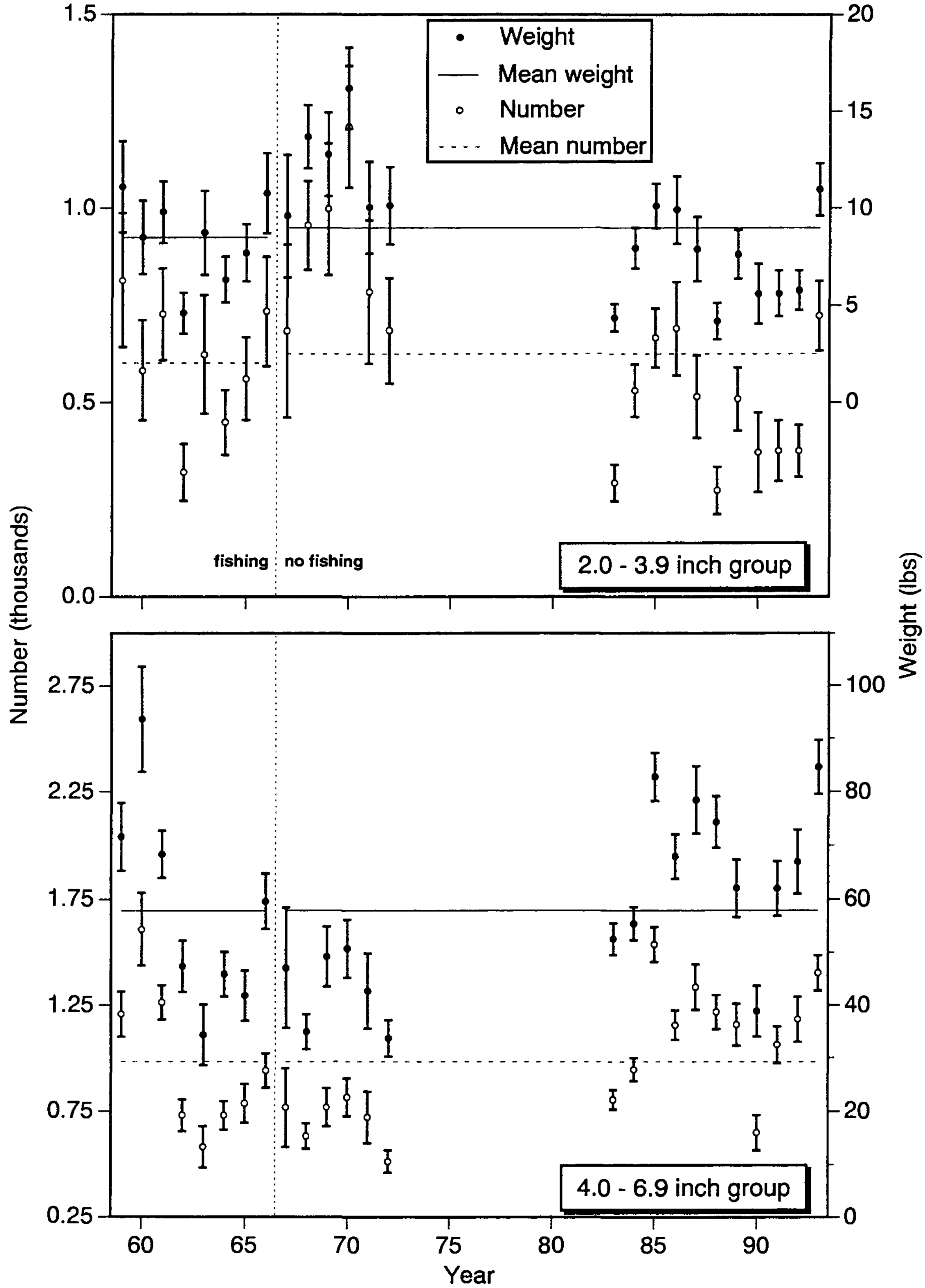

Figure 5.—Spring numbers and standing crops (pounds) of brook trout of various sizes in section ZA of Hunt Creek, 1959-93. Means for the fishing (1959-66) and no fishing (1967-93) periods are shown by horizontal lines. Errors bars represent 2 standard errors.

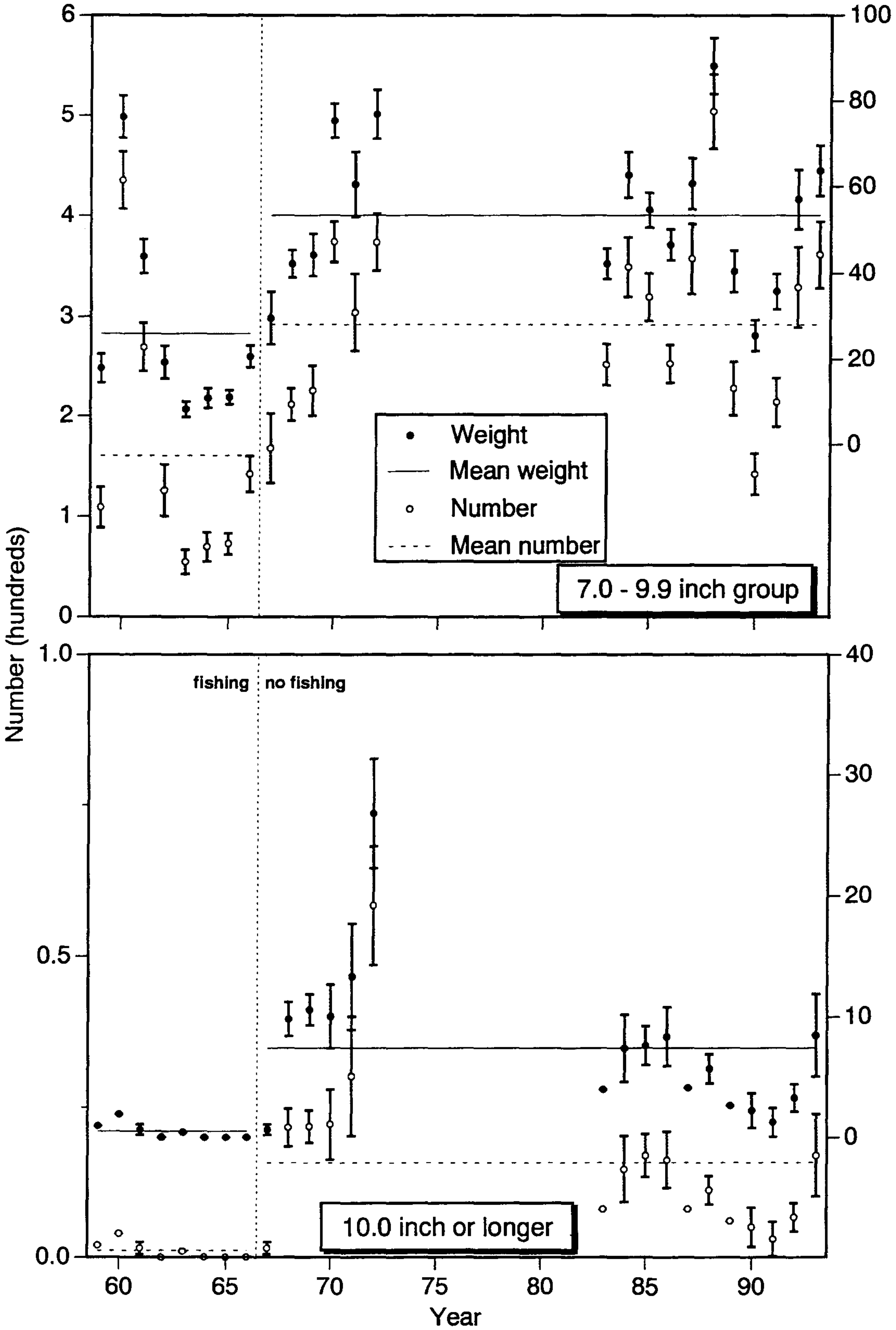

Figure 5.—Continued.

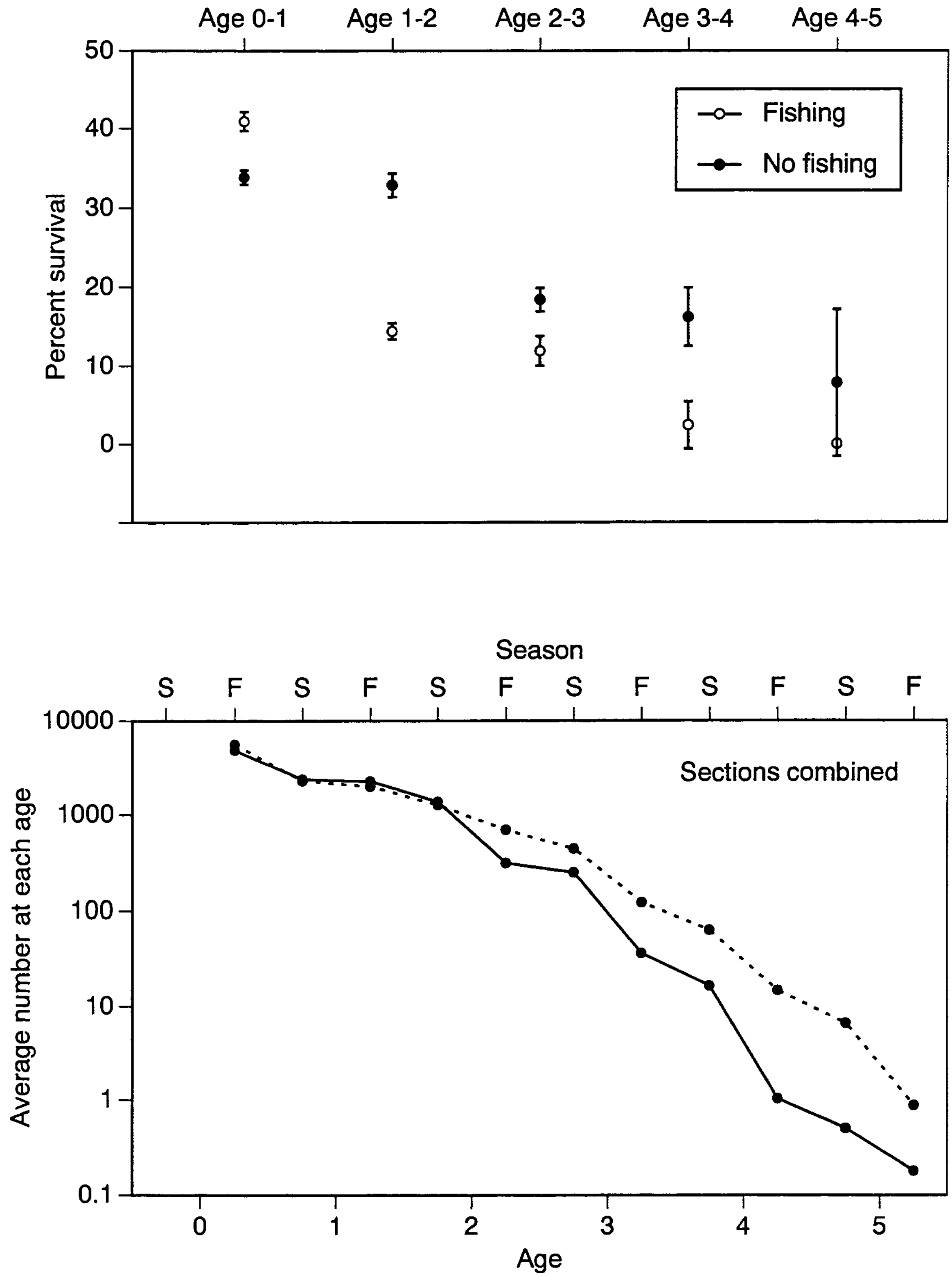

Figure 6.—Survivorship curves of brook trout showing semi-annual survival rates during fishing and no fishing periods in Hunt Creek in stream sections BC, ZA, and for the combined sections (ZABC). The letter S represents spring and F represents fall.

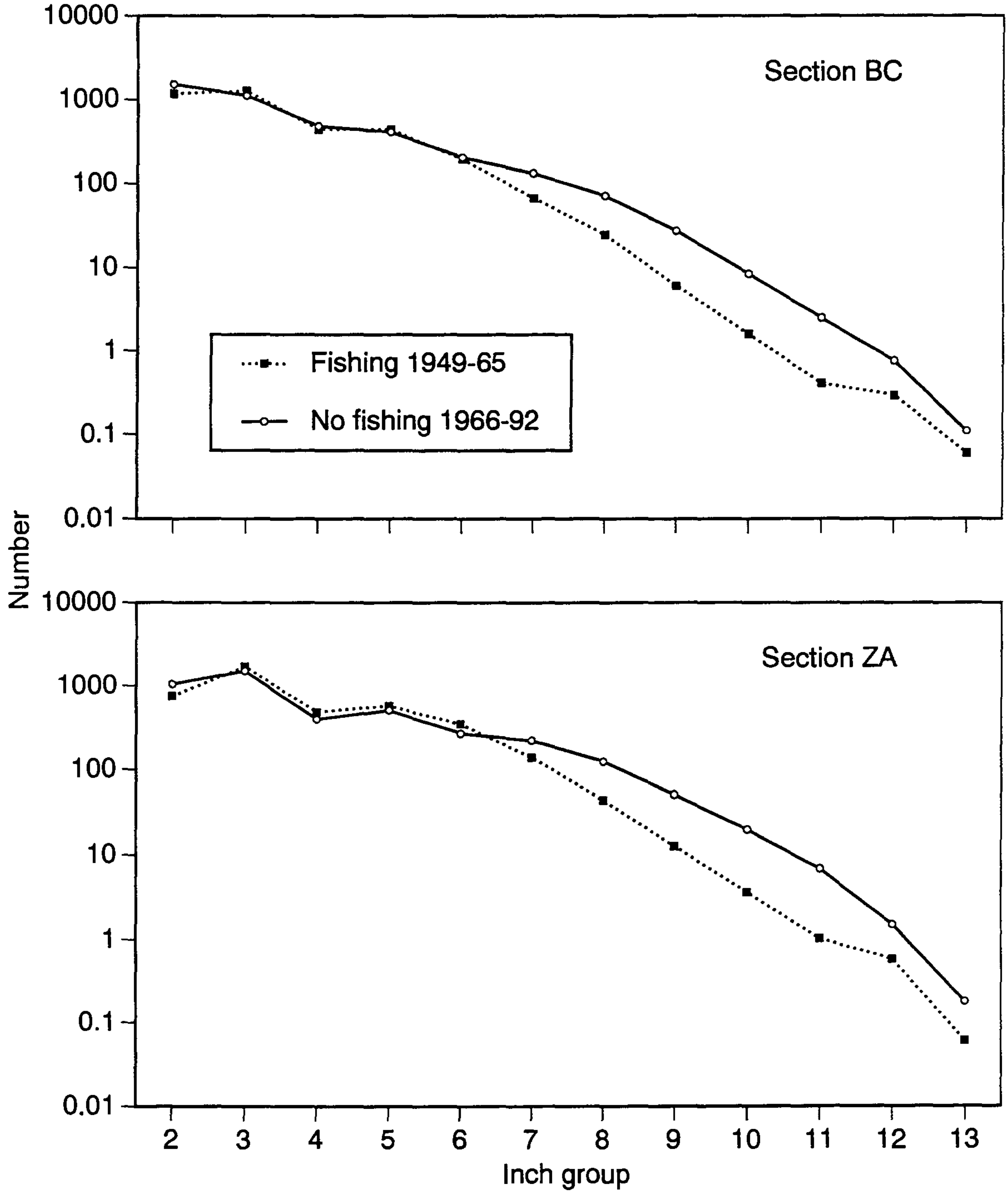

Figure 7.—Mean length-frequency distribution of brook trout during September in sections BC and ZA of Hunt Creek during fishing and no fishing periods.

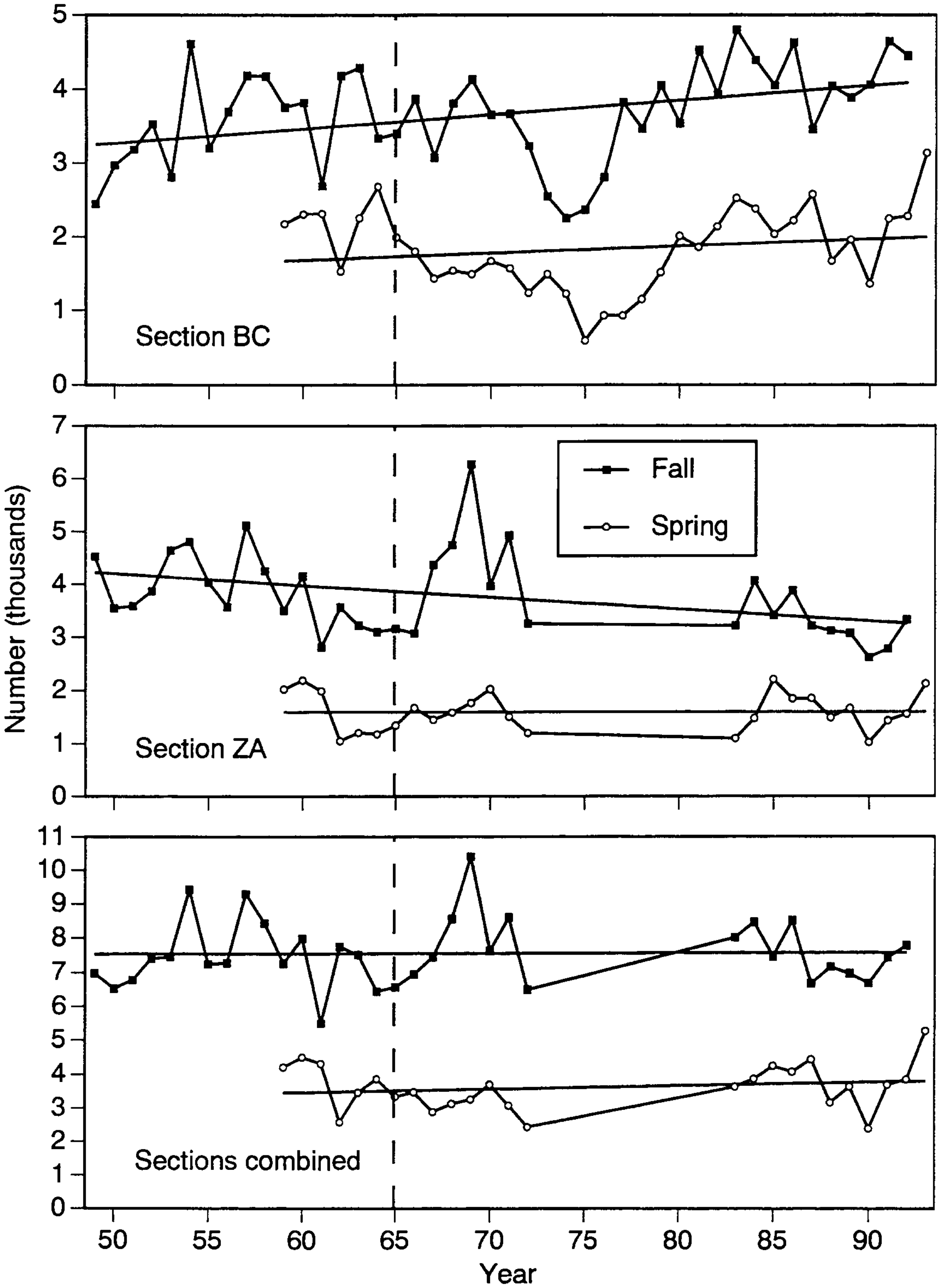

Figure 8.—Spring and fall numbers of sublegal brook trout in sections BC, ZA, and ZABC of Hunt Creek in periods of fishing (1949-65) and no fishing (1966-93). Regression lines shown are for the entire study period.

Table 1.—Mean number of legal sized brook trout present in the fall and mean angler harvest in Hunt Creek, Michigan from 1949-65 and 1966-92. Bounds (95%) on the error of estimation in parentheses.

	Fishing period		No Fishing period	
Section	BC	ZA	BC	ZA
Mean fall population	101 (3)	200 (3)	245 (3)	424 (3)
Mean angler harvest	185 (0)	340 (0)	0 —	0 —
Total	286 (3)	540 (3)	245 (3)	424 (8)

Table 2.—Mean length at age (inches) in fall for age 0-5 brook trout in sections BC and ZA under conditions of fishing (1949-65) and fishing closure (1966-92). The number of years with sample data for that age group is shown in parentheses.

	Age					
	0	1	2	3	4	5
			Section BC			
Fishing	3.08[1] (17)	5.31 (17)	7.22 (17)	9.03 (17)	11.23 (4)	— (0)
No Fishing	2.96[1] (27)	5.23 (27)	7.36 (27)	9.01 (27)	10.71 (23)	11.31 (10)
			Section ZA			
Fishing	3.32 (17)	5.66 (17)	7.42 (17)	9.60 (17)	10.72 (3)	10.50 (1)
No Fishing (1966-72 and 1983-92)	3.23 (17)	5.54 (17)	7.66 (17)	9.42 (17)	11.11 (16)	11.92 (5)

[1]Means significantly different. ANOVA $P \leq 0.05$.

Table 3.—Semi-annual estimates of mean percent survival for brook trout cohorts in sections BC and ZA under conditions of fishing (1959-65) and fishing closure (1966-92). Bounds (95%) on the error of estimation in parentheses.

	Age span	Fishing period	No fishing period
Fall to spring	0 to 1	48.7 (84.3)	39.9 (42.2)
Spring to fall	1 to 1	96.0 (5.4)	89.9 (3.2)
Fall to spring	1 to 2	58.3 (3.2)	61.2 (2.7)
Spring to fall	2 to 2	23.4[1] (2.7)	56.5 (2.7)
Fall to spring	2 to 3	80.5 (13.7)	65.6 (4.0)
Spring to fall	3 to 3	18.0[1] (4.5)	33.2 (3.1)
Fall to spring	3 to 4	78.1 (43.0)	61.5 (8.3)
Spring to fall	4 to 4	9.1[1] (7.8)	26.9 (5.5)

[1]Means significantly different. $P \leq 0.05$.

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