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EFFECTS OF ARTIFICIAL DESTRATIFICATION ON RAINBOW TROUT (SALMO GAIRDNERI RICHARDSON) DEPTH DISTRIBUTION AND GROWTH IN A NORTHERN MICHIGAN LAKE

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ABSTRACT

Rainbow trout (Salmo gairdneri Richardson) showed no dramatic response to the artificial destratification of a small, non-productive Michigan lake. Relative to a summer of normal stratification, their depth distributions were not greatly altered, growth rates of one-year olds were not significantly different, nor did any obvious increase in mortality occur during destratification. Oxygen concentrations were never limiting to the trout either before or during mixing; however, the minimum and average water temperatures were greatly increased by destratification. Minimum temperature increased from less than 8 C to over 23 C during destratification, but temperatures remained sublethal.

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Introduction

Artificial destratification of eutrophic lakes increases space, reduces fish kills caused by oxygen depletion and may increase growth rates (Johnson, 1967; Fast, 1968; Halsey, 1968; Woods, 1961; Rasmussen, 1960; Fast et al., in prep.). Although many eutrophic lakes have been destratified, there are few reported cases of artificially destratified oligotrophic lakes. These lakes typically have high oxygen concentrations below the thermocline, low productivity, and are capable of supporting coldwater fishes year-round.

This study evaluated the effects of artificial destratification on Section Four Lake, an oligotrophic, northern Michigan lake. The lake was studied during the summer 1969 while normally stratified, and during the summer 1970 while artificially destratified, as described by Fast (1971a).

Methods

Section Four Lake was stocked with 1,000 right-pectoral fin-clipped rainbow trout on 6 June 1969. These fish were mostly one-year-olds raised at the Michigan Department of Natural Resources (DNR) trout rearing ponds at Wolverine, Michigan. They averaged 188 mm fork length (FL) and ranged from 160 mm to 280 mm. The fish were released at one point on the shore and only a few dead fish were observed soon after their release.

The lake was again stocked with 1,071 left-pelvic fin-clipped rainbow trout on 23 May 1970. These fish were one-year-olds raised at Wolverine. The fish averaged 200 mm FL (range: 190 mm to 240 mm). They were measured and handled as during 1969, except that they were sorted for larger sizes. This was necessary to assure larger-sized fish than were stocked during 1969. Only 2 of 32 fish captured by our nets during 1969 were less than 200 mm. Only 10% of the fish stocked during 1969 were larger than 200 mm, whereas 35% of those stocked during

1970 were 200 mm or larger. The fish were captured by two vertical gill nets of stretch mesh sizes 19.0 mm and 25.4 mm, respectively. The nets were checked once a day and the depth of capture, fin clip, stomach content and scale sample of each fish were determined and collected.

Section Four Lake contained a residual rainbow trout population in 1969. These fish (3,000 fingerlings, at 2,200/kg) had been stocked annually during 1964 and 1965. These fish averaged 330 mm FL during 1969-70, but were very emaciated. They had no natural reproduction, and most females showed evidence of egg absorption. These fish were not fin clipped, but they were readily distinguishable from fish stocked in 1969 and 1970.

Growth rates were estimated using scales collected ventral to the lateral line and posterior to the pectoral fin. Back calculations were made by the Dahl-Lea method as discussed by Hile (1970). Ages were determined for the 1964-65 trout from 20, 11 and 2 fish captured during 1969, 1970 and 1971, respectively; for the right-pectoral fin-clipped trout, from 12 and 25 fish captured during 1970 and 1971, respectively; for the left-pelvic fin-clipped trout, from 32 fish collected during 1971.

Temperature was measured at least weekly with a resistance thermometer. Oxygen was measured at least weekly using the Alsterberg modification of the Winkler method, except PAO was substituted for thiosulfate, and thyodene was substituted for starch solution. Oxygen and temperatures were measured near the lake's center.

The record of isotherms and trout depth distributions (Fig. 2) was produced with the aid of M.S.U.'s CDC 3600 computer.

Lake description and destratification system

Section Four Lake is located in the Pigeon River State Forest (45.1 N, 84.4 W) about 85 km south of the Straits of Mackinaw, in Otsego County, Michigan. It is nearly circular in outline with circular depth contours, typical of lime sink lakes in this region. Its surface is 1.2 ha; the maximum depth is 19.1 m. There is no inlet or outlet, and the water level is maintained by the groundwater. There are no obvious inflows, and exchange rates between the lake and the groundwater are apparently low.

Section Four is a typical marl lake. It is oligotrophic with plentiful oxygen at all depths. The pH of the water always exceeds 7.0, and alkalinity averages about 190 mg/l. Chara is found throughout the lake, but is especially dense at maximum depth. Rooted macrophytes are sparse and mostly limited to the water's edge. Phytoplankton is sparse, and Secchi disc transparency often exceeds 12 m. The sediments are calcareous.

The system of artificial destratification used on Section Four Lake was similar to the diffuse aerator described by Fast (1968). A plastic pipe (38 mm ID) conducted air to the deepest point in the lake. The distal 19-m section was perforated by 48 holes, (3.2 mm in diameter). A compressor (2.3 m^3/min at 7.05 kg/cm^2) was run generally 8 hours a day, from 12 June 1970 to 7 September 1970.

Results

Section Four Lake stratified normally during 1969. During early June a thermal gradient extended from 3.5 to 12 m (Figs. 1 and 2). Oxygen during this period ranged from 8.7 mg/l at the surface to 9.5 mg/l at the bottom. By September 1969 the thermal gradient extended from 5.0 to 14.5 m, but oxygen was still plentiful at all depths. Oxygen never fell below 4 mg/l at any depth.

Rainbow trout ranged between the surface and bottom during June 1969 (Fig. 2). Later in the summer they were found mostly below 8 m depth. At no time were they caught in water warmer than 19 C. The gill net samples may give a distorted picture however, because of small sample size. Only 32 1969-stocked rainbow trout and 19 1964- and 1965-stocked rainbow trout were caught during 1969. This low capture rate was due both to the small size of the 1969-stocked fish and to scarcity of trout stocked in 1964-65. Clearness of the water of Section Four Lake also contributed to low catch rates.

Before aeration was begun during 1970, the oxygen and temperature profiles of Section Four Lake were similar to the same seasonal profiles of 1969. Surface temperature was higher during 1970, but oxygen concentrations were nearly identical (Figs. 1 and 2). Soon after aeration was begun, the lake became isothermal at about 16 C. Thereafter it remained isothermal, but temperature of the entire lake increased to approximate the 1969 surface temperatures. Bottom temperature reached a 23.3 C maximum during 1970, compared to a normal hypolimnetic maximum of 8 C. Oxygen concentrations were more uniform and higher during artificial aeration. They never fell below 7 mg/l after aeration began.

During early June 1970, the rainbow trout were mostly distributed between the surface and 12 m. Soon after aeration was begun, they redistributed throughout the lake. By early July they were mostly distributed along the bottom of the lake. During 1970 we captured rainbow trout from different plants as follows: 94 from the 1970 stocking, 11 from 1969 stock, and 11 from 1964-65 stock. We caught more of the 1970 fish presumably because of their larger size.

Although rainbow trout were reportedly stocked during 1964 and 1965, we detected only 1965-fish in our samples. These fish grew well their first year (116.4 mm, Standard error = 4.7 mm), but subsequent growth was slow (Fig. 3). During 1969 and 1970 these fish grew only 21.4 mm (SE = 2.2 mm) and 17.8 mm, respectively.

The trout stocked in 1969 and 1970 grew well during their first year in the hatchery:--135.0 mm (SE = 4.9) and 156.3 mm (SE = 6.2 mm). However, their growth rates decreased greatly during their first year in the lake: 58.5 mm (SE = 3.4 mm) and 62.5 mm (SE = 6.2 mm), respectively. There was not a significant difference (t = 0.60, df = 67) between the average growth rates of these age-group-II fish during 1969 and 1970. The two groups of fish, planted in 1969 and 1970, provide the most valid comparison of growth rates during stratified and destratified conditions. However, it is obvious that in each case much of their second year's growth occurred in the hatchery before they were stocked. For example, the total lot of 1969 stocked fish averaged 188 mm FL (160 to 280 mm range) when stocked, but back-calculated lengths for our age-group-I fish averaged only 135 mm (80 to 190 mm range). Similarly, the total lot of 1970 stocked fish averaged 200 mm (190 to 240 mm range) when stocked, but back-calculated lengths for age I averaged only 156 mm (93 to 209 mm range). If we assume that we collected a random sample of each lot and that their average length at stocking was nearly equal to the grand average for the lot, then we see that growth in the hatchery of age-group-II fish for each lot was 53 mm and 44 mm, respectively, for the 1969 and 1970 stocked fish. This indicates that their growth in the lake was only about 3 mm and 18 mm, respectively. It is impossible to check these assumptions and, therefore, impossible to calculate their true growth during their first year in the lake.

Most trout's stomachs were empty when collected. Typical among the limited stomach contents were periphyton, sticks, marl encrustations, miscellaneous detritus, terrestrial insects, amphipods and cladocera. No food item predominated over the others.

Discussion and conclusions

During 1969, the rainbow trout in Section Four Lake lived between the 5-C and 19-C isotherms. They exhibited no clear preference for the 13-C final preferendum temperature indicated by Garside and Tait (1958), or the 18- to 19-C temperatures observed by McCauley and Pond (1971) for rainbow trout. Garside and Tait conducted their laboratory experiments with fish of 100 to 150 mm in length, whereas McCauley and Pond used 40- to 50-mm fish. Although it is known that the reaction of fish to temperature is affected by light (Sullivan and Fisher, 1953; Brett, 1952; Pearson, 1952), by feeding activity (Brett, 1952; Pearson, 1952), and by social behavior (Pearson, 1952), it is uncertain what the major factors were in Section Four Lake. The nature of their diet, their condition, and their slow growth indicate that they were at near-starvation levels. The trout stocked in 1965 were very emaciated. These conditions could lead to a general "search" behavior and thus account in part for their scattered distribution. This distribution is in contrast to that found by Horak and Tanner (1964) in Horsetooth Reservoir, an oligotrophic lake where (as in Section Four Lake) oxygen, pH, carbon dioxide and alkalinity gradients apparently did not affect the depth distribution of rainbow trout. Nevertheless, the trout in Horsetooth Reservoir preferred water between 18.9 C and 21.1 C, with more than 93% found in or above the thermocline. The predominant factor affecting their distribution in Horsetooth Reservoir appeared to be food distribution. The trout fed predominantly on cladocera, which were most abundant in the epilimnion. We did not measure depth distribution of cladocera in Section Four Lake, but cladocera were not a major food item.

The intensity of the thermal gradient could be an important factor affecting the depth distribution of fish. In Section Four Lake during 1969, this gradient was relatively weak, as is typical of sheltered lakes, and was not a strong barrier to fish movement. Using the definition of the thermocline as a change of 1 C per meter of depth, the thermocline on some dates begins at the surface and extends to near the bottom. Although no one has clearly described responses of rainbow trout to different intensities of temperature gradient, other organisms react abruptly to strong thermal or density gradients (Beeton, 1960; Harder, 1968). Burbidge (1969) found that rainbow smelt (Osmerus mordax) would not penetrate strong thermal gradients in the thermocline.

Although trout were not captured near the surface after early July 1969, they were seen to feed at the surface after that period. Likewise, terrestrial insects and surface-living insects were found in their stomachs. This indicates that, although they avoided prolonged periods in shallow water, the trout resided mostly in the deeper water and made feeding excursions into shallow water. Because of the water clarity, they could undoubtedly see surface disturbances from some depth. Likewise, they may have seen the nets better in shallow water and avoided them more effectively than in deep water.

Although trout were distributed throughout the lake during artificial destratification (in 1970), they showed a preference for the bottom. Food does not appear to have been an important factor affecting this distribution, since their diet (in 1970) was essentially the same as during 1969. Their abundance in deep water may have been a thwarted attempt to seek cooler water, since, before aeration, cooler water could be encountered by swimming downwards.

Many trout concentrated in the rising air bubbles. Fast (1971b) described this same response by threadfin shad (Dorosoma petenense) in a southern California reservoir. In the case of shad, their aggregation was thought to be a rheotactic response which was reinforced, or rewarded, by high concentrations of food in the rising water. If zooplankton concentrated along the bottom of Section Four Lake, this rising water undoubtedly contained higher concentrations than did the surface waters. Trout which aggregated in the rising water might thus be exposed to higher food concentrations than were surface-dwelling trout.

Although the effect of lake-mixing on the growth rate of fish stocked during 1969 and 1970 is confounded with growth prior to stocking, there did not appear to be a significant difference in growth due to the destratification. It appears that most of the growth of age-group-II fish stocked during 1969 and 1970 occurred in the hatchery, but this cannot be substantiated. Based on the observed growth rates, on stomach contents of the fish, and on their general condition each year, we believe that destratification did not materially affect their growth one way or the other. This is in keeping with similar inconsequential effects of the destratification on standing crops of phytoplankton and zoobenthos (Fast, 1971a; Fast et al., in press).

Since artificial destratification increases the lake's heat budget, and eliminates the deep, cold water, this poses a thermal threat to the rainbow trout (Fast, 1968; Fast and St. Amant, 1971). Although trout can withstand 26.7 C temperatures for a few days, prolonged temperatures above 24 C lead to high mortalities (Eipper, 1960), and 100% mortality can be expected at 27 C over 24 hours regardless of acclimation temperatures (Charlon et al., 1970). During a summer of continued aeration the entire lake will become about as warm as the surface waters during a summer of normal stratification. If the surface waters normally attain 26 C or more during the summer, the entire lake may become this warm. Normally Section Four Lake has a maximum epilimnetic temperature between 23 C and 25 C. With continuous air injection during 1970, the entire lake was over 23 C for about 2 weeks during August. Charlon et al. (1970) observed a 4.4% mortality in acclimating rainbow trout to 23 C for 1 week. This rate increased to 13% at 26 C, and 100% at 26.5 C. No trout mortalities in Section Four Lake were observed during this period, nor did the fish appear otherwise adversely affected, indicating that lethal conditions were not created.

From the fisheries standpoint, artificial destratification of oligotrophic lakes is generally not advisable, since such mixing will increase their heat content and eliminate the lakes' cold water. Such heating can lead to the elimination of coldwater species such as trout. Either eutrophic or oligotrophic lakes with borderline or sublethal surface temperatures, such as Section Four, are possible exceptions. Destratification of certain of these lakes may increase the production of fish food and trout.

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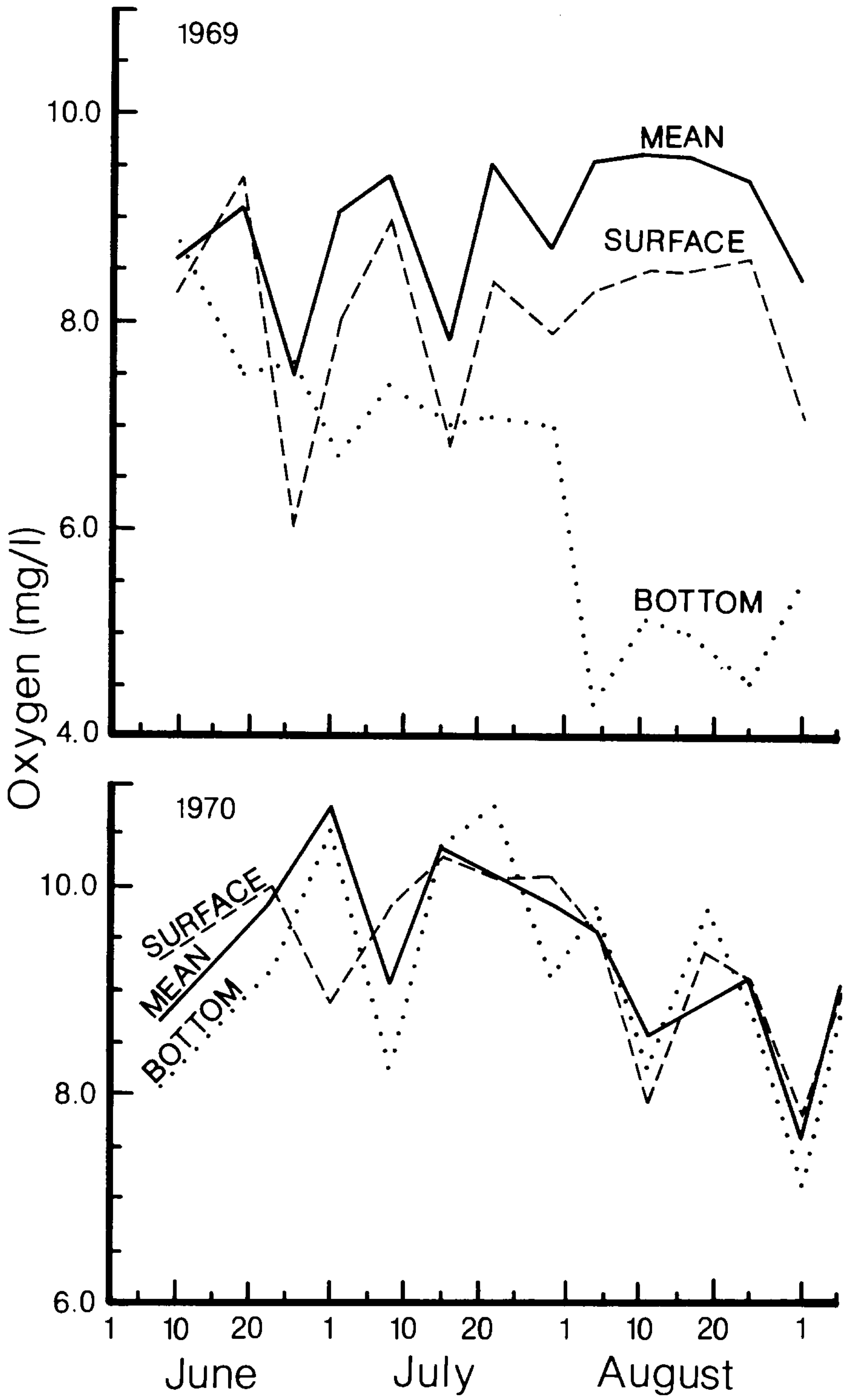

Figure 1.--Surface, bottom and mean oxygen concentrations during the summers 1969 and 1970 in Section Four Lake. Aeration occurred between 16 June and 7 September 1970.

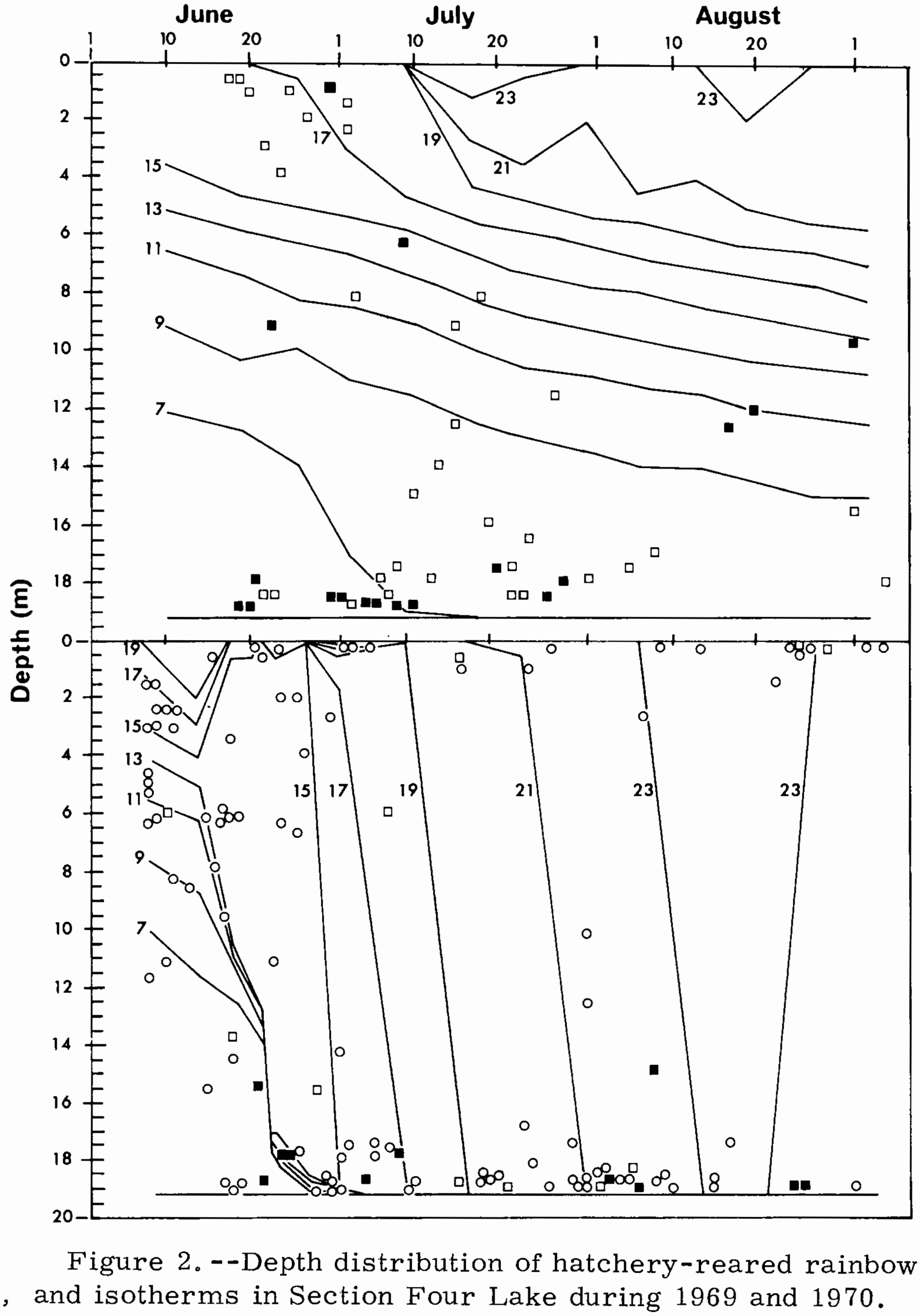

Figure 2. --Depth distribution of hatchery-reared rainbow trout, and isotherms in Section Four Lake during 1969 and 1970.

Upper figure is for 1969; open squares are fish stocked in 1969; solid squares are fish stocked during 1964-65.

Lower figure is for 1970; open circles are fish stocked in 1970; open squares are fish stocked in 1969; solid squares are fish stocked in 1964-65. Each symbol represents one fish; the isotherms are in degrees C.

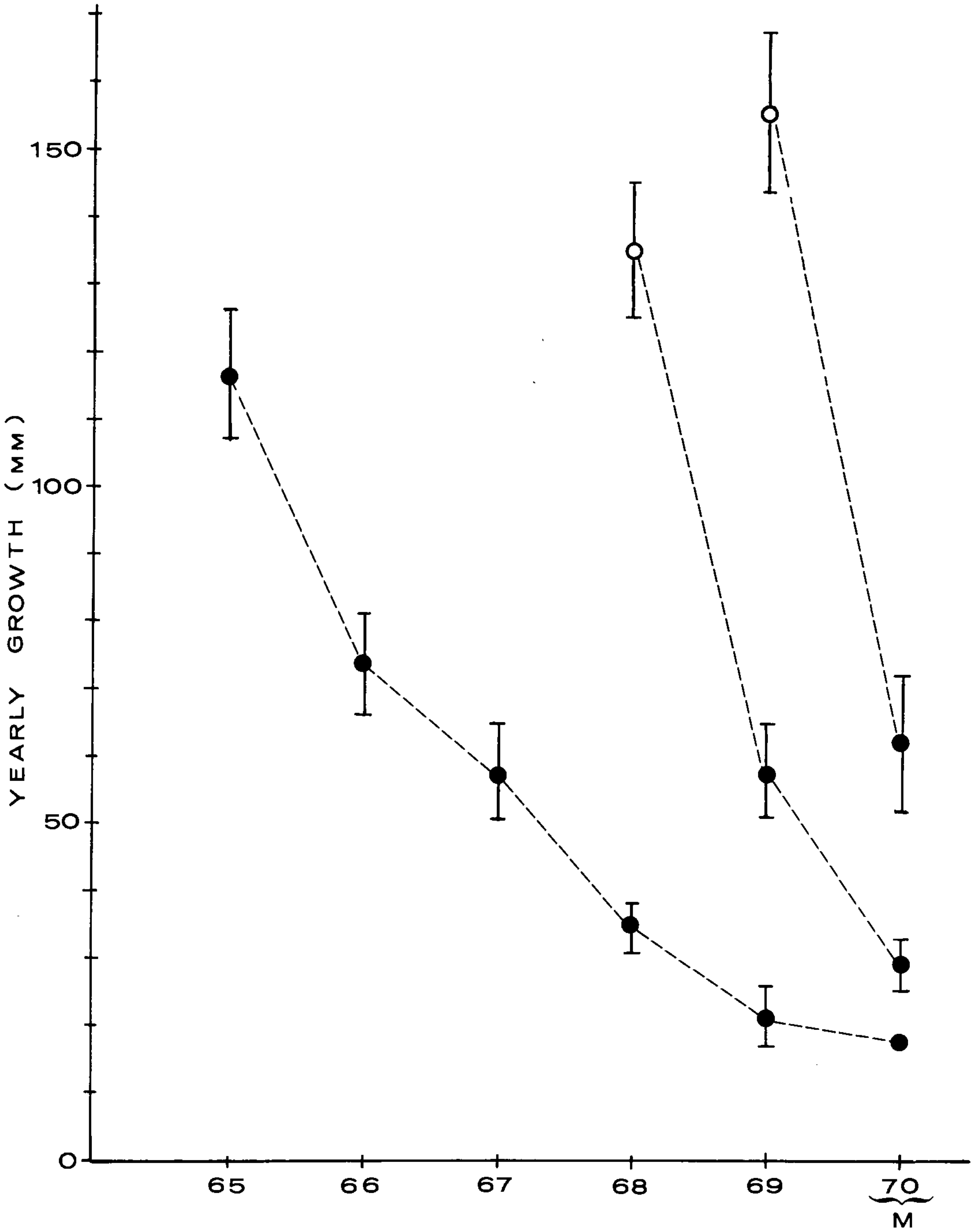

Figure 3.--Yearly growth rates with 95% confidence intervals for rainbow trout in Section Four Lake. The 1965, 1968 and 1969 year classes are shown. Open circles represent growth in the hatchery; solid circles represent growth which was totally in the lake, or a year's growth in the lake and hatchery combined. The lake water was artificially mixed during 1970.

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