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The Effect of Grass Carp Introduction on Aquatic Vegetation and Existing Fish Populations in Two Small Prairie Lakes

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THE EFFECT OF GRASS CARP INTRODUCTION ON AQUATIC VEGETATION AND EXISTING FISH POPULATIONS IN TWO SMALL PRAIRIE LAKES

BY

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Abstract

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Within two years after triploid grass carp introduction in 2.3 hectare Prior Lake in South Dakota, aquatic vegetation coverage and height in the water column were significantly lower ($P<0.005$). During the same two year period, triploid grass carp did not significantly reduce aquatic vegetation coverage or height in the water column in 11.4 hectare East Lake Eureka, also in South Dakota. Stocking densities were 49 fish/hectare and 61 fish/hectare (229 mm mean total length) in Prior Lake and East Lake Eureka, respectively.

The biomass of prey fish in East Lake Eureka in 1986 was quite high with 88.3, 85.3 and 17.3 kg/hectare for black bullhead (*Ictalurus melas*), yellow perch (*Perca flavescens*), and bluegill (*Lepomis macrochirus*), respectively. The biomass of northern pike (*Esox lucius*) was also high at 13.8 kg/hectare. A Proportional Stock Density (PSD) of 11 and Relative Weight (W_r) of 117 indicated a relatively healthy bluegill population in East Lake Eureka. However, the PSD value for black bullheads was lower (8) while their condition was relatively good ($K=1.58$). The yellow perch

population appeared to be over-populated in East Lake Eureka with a PSD of only 5 and a relatively low condition factor (K=1.14). The northern pike population in East Lake Eureka had a PSD value of 53, but a slightly low W*r* of 94. Available prey/predator ratio indicated that there was an excess of prey fish for most size classes of predators. Because no significant vegetation reduction occurred in East Lake Eureka, no changes in existing fish populations could be attributed to grass carp introduction or aquatic vegetation reduction. Data gathered on existing fish populations in East Lake Eureka will serve as a pre-treatment data set to be compared to future conditions if aquatic vegetation is reduced. Fish sampling in Prior Lake was greatly reduced due to a winterkill which occurred in the late winter of 1986.

Bluegill and largemouth bass (*Micropterus salmoides*) were the most abundant fish species found in Prior Lake in 1987. Bluegill appeared to be overpopulated as their PSD value was 1; a high W*r* of 109 may have indicated improved conditions immediately following the winterkill. Results for the largemouth bass in Prior Lake were similar with a low PSD (7) and a high W*r* (112).

Winterkill (Prior Lake) and lack of aquatic vegetation control by grass carp (East Lake Eureka) prohibited making conclusions about the effect of grass carp introduction on the existing fish populations in the two lakes. Further research needs to be conducted in South Dakota to determine appropriate grass carp stocking rates for South Dakota waters, and to evaluate what effect grass carp introduction and aquatic vegetation reduction has on existing fish populations.

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. David W. Willis Date
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INTRODUCTION

Native to large, slow-moving rivers in China (Cross 1969; Shireman and Smith 1983), grass carp (*Ctenopharyngodon idella*) were first introduced into the United States in 1963 by the U. S. Fish and Wildlife Service for evaluation as an aquatic weed control agent. Grass carp have since been distributed throughout the country, and occurrences of the fish in the wild are reported from many areas, most notably in the Mississippi and Missouri River drainages (Guillory and Gasaway 1978).

Since their introduction, grass carp have demonstrated effective control of aquatic macrophytes (Fowler and Robson 1978; Colle and Shireman 1980). Grass carp caused a 91% reduction in aquatic vegetation biomass in three years in a small Iowa reservoir (Mitzner 1978). However, grass carp select preferred plant species, resulting in non-uniform removal of aquatic vegetation. Among the most preferred plants consumed by grass carp are some species of *Potamogeton*, *Chara*, and *Najas* (Cassani and Caton 1983; Harberg and Modde 1985). *Ceratophyllum demersum* and *Myriophyllum* spp. are examples of plants that are not readily consumed by grass carp (Wiley et al. 1986; Wiley et al. 1987).

Preferred plant species seem to be chosen on the basis of succulence (Prowse 1971) and ease of handling (Wiley et al. 1986). Therefore, grass carp tend to consume preferred plant species first and then switch to less desirable species only when the former are exhausted (Cassani and Caton 1983; Wiley et al. 1986). Fowler and Robson (1978) suggested stocking sufficient numbers of grass carp to consume both the initial biomass of preferred plants and the subsequent increase in biomass of species of lower palatability.

Because of the potential negative impacts from natural reproduction of grass carp (Gasaway and Drda 1977; Hardin et al. 1984), much interest has been shown in sterile forms (Stanley 1976; Cassani and Caton 1985). Hybrid grass carp, female grass carp crossed with male bighead carp (Hypophthalmichthys nobilis), also consumed aquatic vegetation but at rates somewhat lower than grass carp (Cassani and Caton 1983; Freeze and Henderson 1983; Harberg and Modde 1985; Wiley et al. 1986). All-female populations (monosex) of grass carp can substantially reduce aquatic vegetation (Young 1986), and triploid grass carp have also demonstrated effective aquatic vegetation control (Wiley and Gorden 1984).

Aquatic macrophyte removal by grass carp influences water quality (Lembi et al. 1978). Typically, decreased pH, increased alkalinity, and increased turbidity are reported following grass carp introduction (Rottman and Anderson 1977; Wiley and Gorden 1984). Higher nitrogen and phosphorus levels are commonly found following grass carp introduction and subsequent aquatic macrophyte reduction (Cassani and Caton 1985). However, Mitzner (1978) found lower nitrate and nitrite concentrations and no significant changes in phosphorus levels in a small impoundment in the years following grass carp introduction. Mitzner (1978) concluded that aquatic vegetation control by grass carp did not necessarily accelerate eutrophication by releasing nutrients into the system.

Fish food organisms such as macroinvertebrates also are influenced by vegetation reduction. A decrease in diversity of macroinvertebrates occurred after vegetation removal by grass carp in three Florida lakes (Gasaway 1979). However, Cassani and Caton (1985) observed an increase in numbers of some macroinvertebrate species after vegetation reduction in other Florida lakes. Hardin (1980) found an increase in some benthic macroinvertebrate species while other species associated with plants declined as vegetation coverage declined.

These ecosystem changes following grass carp introduction and aquatic vegetation reduction then affect native fish populations. Rottman and Anderson (1977) reported a 270% increase in fathead minnow (Pimephales promelas) and bluegill (Lepomis macrochirus) production in ponds stocked with grass carp. Buck et al. (1975) also found the highest production of small bluegill occurred in pools with weed control by grass carp. Improved feeding efficiency of fingerling channel catfish (Ictalurus punctatus) and striped bass (Morone saxatilis) was noted by Kilgen (1978) following water hyacinth control by grass carp. A 140-2,500% greater fall standing stock of smallmouth bass (Micropterus dolomieui) was found in small ponds with grass carp compared to control ponds (Baur et al. 1979). In the same study, Baur et al. (1979) concluded that grass carp had no adverse effect on young of the year bluegill and largemouth bass (Micropterus salmoides) survival unless the aquatic vegetation was greatly reduced, in which case these small fish were more vulnerable to predation by larger largemouth bass. Channel catfish and largemouth bass production was higher in Illinois ponds with the highest densities of grass carp while bluegill production was reduced in the same ponds (Wiley and Gorden 1984). Lower standing stocks of bluegill in ponds with grass carp also were reported by Forester and Lawrence (1978); however, lower bluegill standing stocks also occurred in ponds with common carp (Cyprinus carpio), and the reduction was believed to be caused by carp and grass carp disruption of bluegill spawning activity. In Florida lakes the condition factors of bluegill, redear sunfish (Lepomis microlophus), and largemouth bass were reduced after Hydrilla growth became excessive; reduction of this Hydrilla by grass carp and herbicides resulted in improved condition factors for these fish (Colle and Shireman 1980). Colle and Shireman (1980) concluded that some Hydrilla (coverage less than or equal to 30%) was beneficial for sportfish populations, and that Hydrilla height in the water column affected bluegills and redear sunfish more than Hydrilla coverage. In another Florida study, the threadfin shad (Dorosoma petenense) population increased following Hydrilla removal by grass carp, and improved foraging conditions for black crappie (Pomoxis nigromaculatus) which then resulted in increased growth rates (Maceina and Shireman 1982). Bailey (1978) surveyed past fisheries data for 31 Arkansas lakes and reservoirs in which grass carp had been stocked; these lakes varied greatly in vegetation coverage and grass carp stocking rates, and the results of grass carp introduction also varied greatly. He concluded that grass carp introduction and aquatic vegetation removal did tend to improve condition factors for largemouth bass, bluegill, and redear sunfish, but other factors may have had greater impacts on the fish populations than did the grass carp. Mitzner (1978) noted that aquatic vegetation control by grass carp did not seem to influence angler catch rates, but it did improve the satisfaction of shore anglers. One study in Florida noted negative changes in native fish populations following grass carp introduction; high stocking rates of grass carp eliminated aquatic vegetation and resulted in lower largemouth bass production and population size, overcrowding of bluegills, drastic decline or elimination of some endemic species, and increased coarse fish abundance (Ware and Gasaway 1977).

In South Dakota, research on grass carp has been directed toward their use in controlling aquatic vegetation. The grass carp X bighead carp hybrid in South Dakota ponds consumed aquatic vegetation at a rate one-third of that commonly reported for grass carp (Harberg and Modde 1985). In another pond study, monosex (all-female) grass carp removed substantially, but not significantly, more aquatic vegetation than hybrid grass carp (Young 1986). Largemouth bass and bluegills were stocked into the ponds in the Young study; however, no changes in the predator-prey ratios or survival of largemouth bass could be attributed to the aquatic vegetation control by grass carp.

The changes in a native fish community after grass carp introduction may be attributed to changes in water quality, habitat, or biological interactions (Gasaway 1979, Shireman and Smith 1983). However, few conclusions can be made on the direct or indirect effects of grass carp introduction on native fish populations. Most of the work cited previously dealt with grass carp in small hatchery ponds, and the introduction of grass carp and subsequent aquatic vegetation reduction seemed to have a positive effect on the production of other fishes in such ponds (Buck et al. 1975; Rottman and Anderson 1977; Kilgen 1978; Baur et al. 1979). Unfortunately, research on larger bodies of water with native fish populations has not indicated definite trends in fish populations after grass carp introduction. The effects of vegetation removal on an aquatic system and fish community are complex and long range, and for this reason, studies have lacked definite conclusions on the effect of vegetation removal by grass carp on existing fish populations. The purpose of this study was to evaluate the changes in aquatic vegetation levels and existing fish populations in two South Dakota lakes following grass carp introduction.

STUDY SITES

East and West Lake Eureka are located adjacent to the municipality of Eureka, McPherson County, in north central South Dakota. The combined area of both lakes is 40 hectares (140 acres), with East Lake Eureka being 11.4 hectares (40 acres) in size. Both lakes are utilized for fishing and boating, while swimming is allowed at the east lake. Excessive amounts of aquatic vegetation had been a chronic problem at Lake Eureka, especially in East Lake Eureka detracting from its recreational and aesthetic value.

East and West Lake Eureka both had yellow perch (Perca flavescens), black bullhead (Ictalurus melas), bluegill, and northern pike (Esox lucius), and banded killifish (Fundulus diaphanus) as the most abundant fish species. Walleye (Stizostedion vitreum vitreum), largemouth bass (Micropterus salmoides), and orangespotted sunfish (Lepomis humilis) also were found in Lake Eureka. Conductivity levels in East Lake Eureka were high (3,000-4,000 micromhos/cm), which often made electrofishing difficult.

Prior Lake is located within the town of Woonsocket, Sanborn County, in east central South Dakota. Prior Lake is 2.3 hectares (8 acres) in area. Prior Lake also is important to the community as a place to boat, fish, and swim, as well as being aesthetically pleasing. Aquatic vegetation had been a problem at Prior Lake, covering a large part of the lake surface.

The most abundant fish species in Prior Lake were largemouth bass, bluegill, and green sunfish (Lepomis cyanellus). In addition, black crappie, common carp, and yellow perch were present in smaller numbers. In the early spring of 1986, a partial winterkill occurred in Prior Lake. Because the winterkill would confound the impacts of grass carp introduction and subsequent vegetation removal on the existing fish populations, only limited fisheries sampling was undertaken at Prior Lake. However, aquatic vegetation monitoring was continued.

METHODS

In 1985, East and West Lake Eureka were divided by a screen barrier in the channel connecting the two lakes. Likewise, a screen was placed in the outflow of Prior Lake before grass carp introduction to keep the grass carp confined.

Following the placement of the screen barriers, triploid grass carp were stocked into East Lake Eureka and Prior Lake in June 1985. These fish were approximately 229 mm (9 in) total length (TL) and were stocked at a density of 61 fish/hectare (25 fish/acre) and 49 fish/hectare (20 fish/acre) in East Lake Eureka and Prior Lake, respectively.

Aquatic vegetation levels were monitored in East and West Lake Eureka and Prior Lake through the summers of 1985-1987. A Lowrance X-15 chart recorder was used along standard transects to measure the coverage and height of aquatic vegetation. Six transects were established on East Lake Eureka and four on West Lake Eureka (Figures 1 and 2). Prior Lake had five transects (Figure 3). All of the transects were defined by previous researchers, and were spaced to cover most areas of the lakes as well as being easy to locate and follow.

Aquatic vegetation was monitored during the growing season on all three lakes. Vegetation transects were graphed at all three lakes on two occasions in 1985, prior

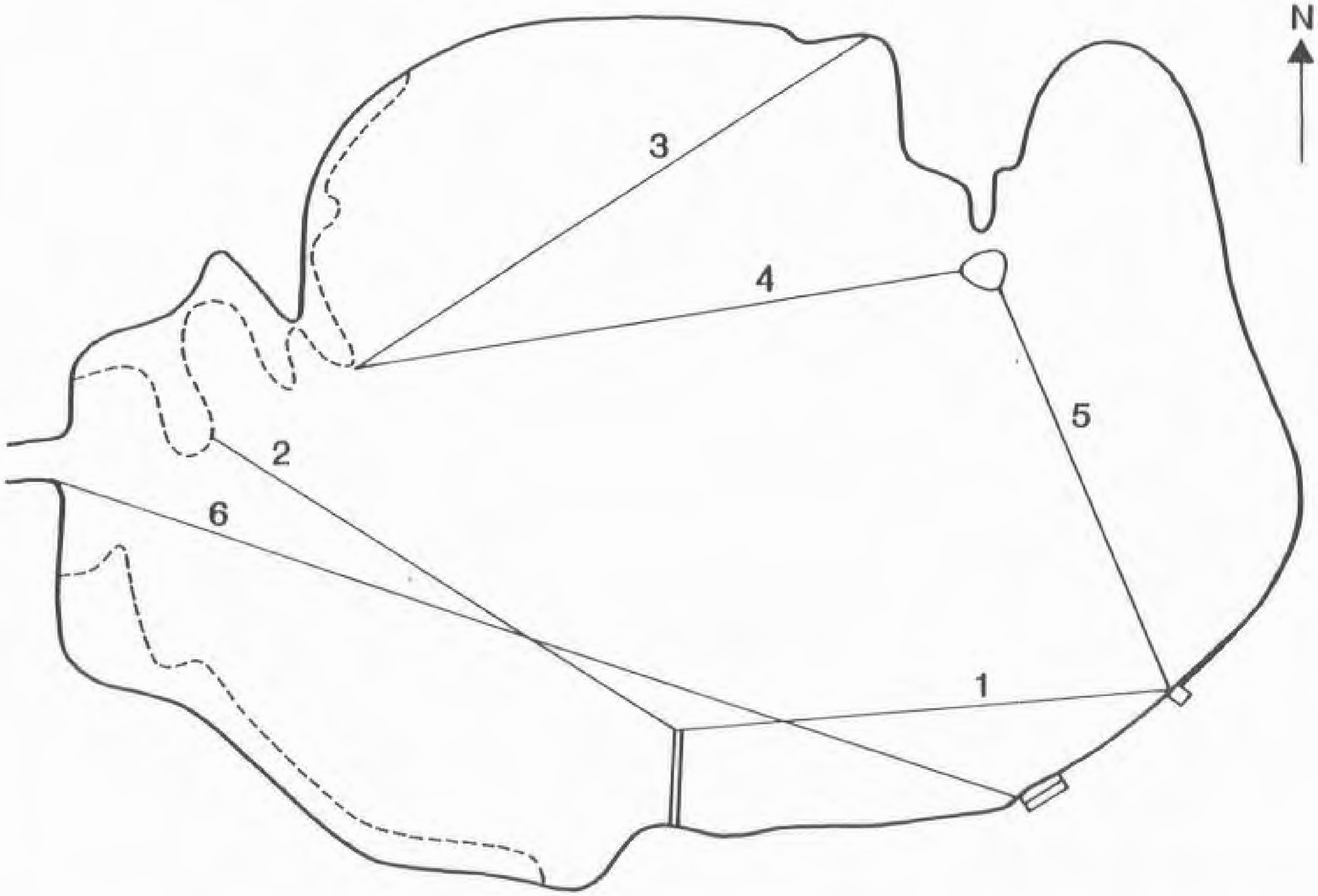

Figure 1. The six aquatic vegetation transects monitored on East Lake Eureka, South Dakota, for vegetation height and coverage estimates. Dotted lines refer to the outer edge of cattail growth.

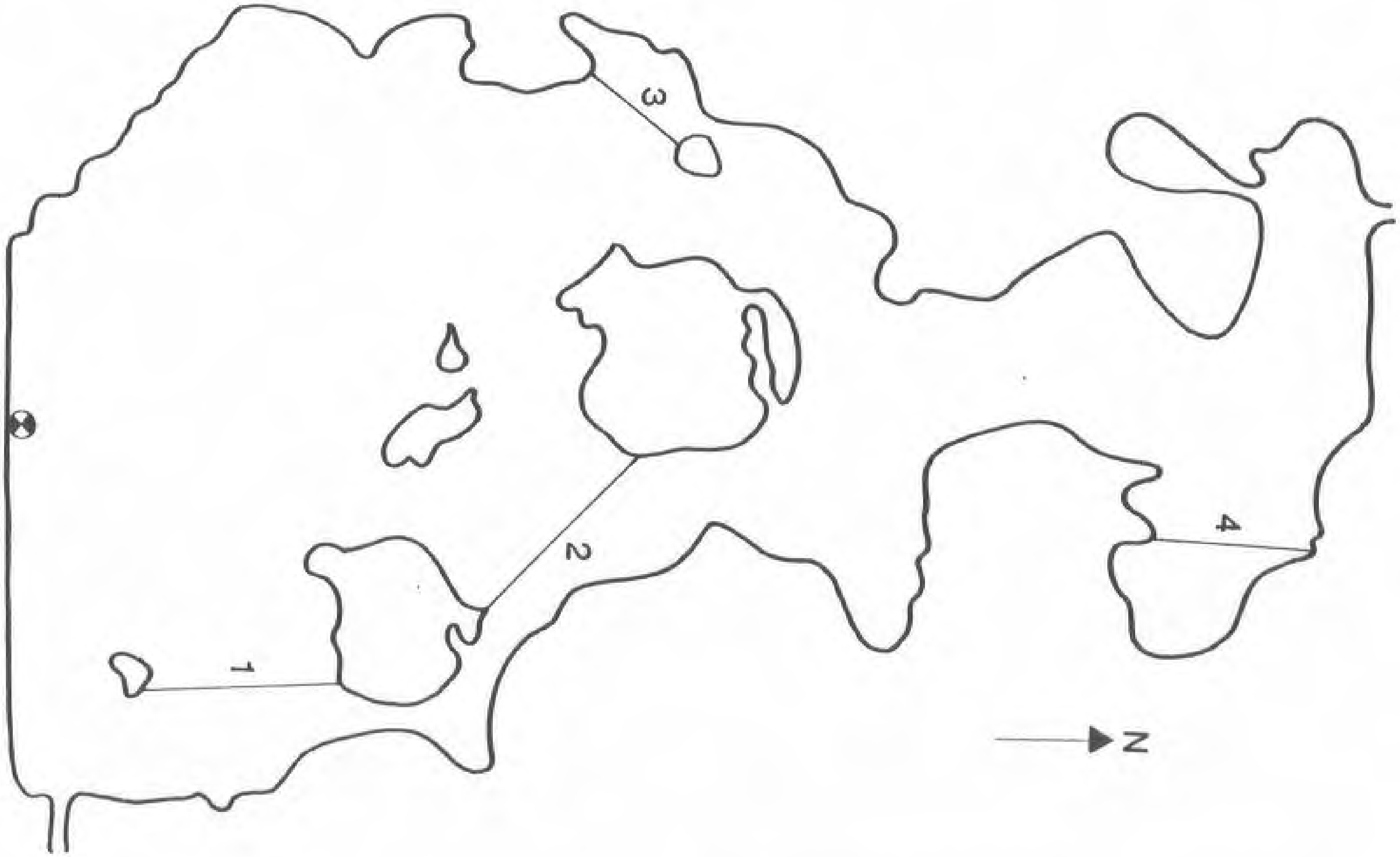

Figure 2. The four aquatic vegetation transects monitored on West Lake Eureka, South Dakota, for vegetation height and coverage estimates.

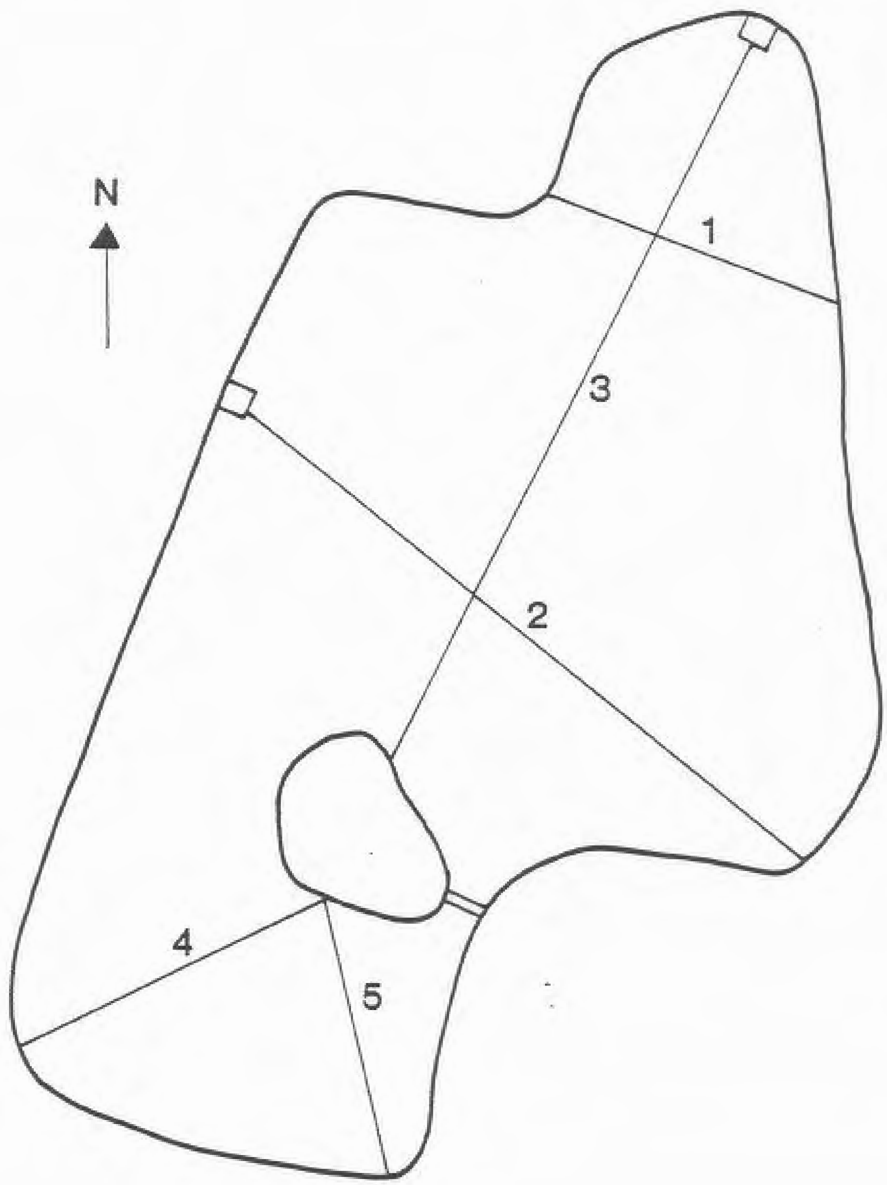

Figure 3. The five aquatic vegetation transects monitored on Prior Lake, South Dakota, for vegetation height and coverage estimates.

to and after grass carp introduction. Throughout the summers of 1986 and 1987 aquatic vegetation was measured every three weeks beginning in mid-May. Aquatic vegetation levels were measured on five occasions during the summer of 1986 and on six occasions during 1987. Concurrent with aquatic vegetation measurements, water transparency was measured with a Secchi disk.

Aquatic vegetation coverage and height were measured from the chart recorder traces of each transect. The total length of each transect was measured as a straight line length of the graph of that transect. Then the amount of the bottom covered by aquatic vegetation was measured along the same straight line. Percentage of the bottom covered by aquatic vegetation was then calculated from these measurements. Therefore, percent vegetation coverage of the bottom was determined for each transect for each date, and the mean of all transects for each date for that particular lake was also calculated.

Aquatic vegetation height was also measured from the chart recorder graphs. Stations along each transect were chosen to fall within sections of the bottom that were vegetated during peak vegetation levels. The stations were chosen at random within each vegetated section. Because of the variability of boat operation and graph recorder operation during transect running, the location of each station was established as a percent of the transect length beginning on one end. For example, station 1 of transect 1 was located at a point 11% of the transect length from the east end. At each station, the total depth was measured from the graph, and the height of the aquatic vegetation from the bottom to the plant tops was also measured. These two values were then used to calculate the percent of the water column occupied by aquatic vegetation. The mean aquatic vegetation height/water column depth values were then determined for each transect and for all transects on each date for each lake.

Statistical analysis of aquatic vegetation levels was made by analysis of variance. A fixed effects model, one-way analysis of variance was utilized to compare vegetation levels between years on both East Lake Eureka and Prior Lake.

Sampling of the existing fish populations was done on East Lake Eureka and, to a lesser extent, Prior Lake. Most sampling data were collected with trap nets having 19-mm mesh (bar measure). In East Lake Eureka, trapnetting was carried out during the month of June in 1985-1987; however, the 1985 data were limited as few fish were captured and lengths and weights were the only data collected. In the following years, trapnetting was continued until population estimates could be made; this amounted to 7 nights (35 total net nights) of trapnetting in both June 1986 and June 1987. Trap nets were set in the evening and checked as soon as possible the next morning. Nets were set perpendicular to shore with the lead staked to the shoreline, and the cod end of the net was set so there was no more than 0.6 m of water over the front frame. Because of the steep banks at Lake Eureka, there were a limited number of sites for trap net sets; therefore, random selection of sites was not possible. On East Lake Eureka, the five trap nets used in each overnight set were spaced at least 100 m apart to avoid overlap in sampling effort. Nets also were moved around the lake on different nights to cover all possible sampling sites. At Prior Lake four trap nets were set for one night in May 1985; this was repeated again in May 1987. Trap nets were set in the same locations in both cases.

Electrofishing also was used to sample fish. A boat electroshocker using AC current was used at night along the perimeter of the lake. Electrofishing did not begin until at least 20 minutes after sunset; sampling was then continued for 30-minute intervals until the entire perimeter of the lake was sampled. Electrofishing was done on East Lake Eureka for two nights in both June 1986 and 1987. Electrofishing was conducted in the same fashion for one night in May 1985 and one night in May 1987 on Prior Lake. High conductivity (4,050 micromhos/cm) made electrofishing impossible on East Lake Eureka in 1985, and only limited electrofishing could be completed in 1986. Conductivity levels decreased to 3,050 micromhos/cm in 1987 and electrofishing was possible.

To catch additional fish, the channel between East and West Lake Eureka was seined. A 61.0- x 2.4-m, 12-mm mesh (bar measure) beach seine was used to block the channel where it leads into East Lake Eureka. The seine was then pulled toward the West Lake to the barrier dividing the two lakes, where it was gathered. The channel was seined on two occasions in June of 1986 and 1987; however, seining in 1987 was hampered by aquatic vegetation growth. In addition, in August 1986 and 1987 a 4.6- x 1.2-m, 3.2-mm mesh (bar measure) beach seine was used at night in the shallows on East Lake Eureka to capture small fish. Seining was conducted at locations on East Lake Eureka where the banks were shallow enough for wading. At each location one end of the seine was held stationary at the water edge while the net was stretched tight and then swept in a 180° arc. This inshore beach seining was done on two nights in August 1986 and two nights in August 1987.

One other technique was used to capture fish in East Lake Eureka. Angling was used to a limited extent in 1986 and 1987 in order to specifically capture yellow perch and bluegill from some of the shallow, heavily vegetated areas around East Lake Eureka.

Data were gathered from all fish collected by the various sampling techniques. Small fish captured by inshore beach seining were measured in centimeter length groups. For all other sampling, the first 10 fish in each centimeter length group were weighed to the nearest gram and measured to the nearest millimeter. Scales or spines also were collected from these fish. Fish in excess of 10 individuals were only measured to the nearest centimeter. All fish captured in East Lake Eureka except those captured by inshore beach-seining were marked before release. Adipose fins were clipped to mark black bullheads, while all other fish were marked with a fin punch of the soft dorsal fin. All fish were handled as rapidly and carefully as possible. Anesthetic (MS-222) was used to make fish handling easier. Fish usually were released from a central site such as the boat ramp or middle of the lake; occasionally fish would be released immediately after handling at the capture site.

In 1987 head widths of predatory fishes were measured to determine maximum prey sizes that could be ingested by the predatory fish. Northern pike, large black bullhead (TL>265 mm), and large yellow perch (TL>200 mm), head widths were measured to the nearest millimeter using calipers. Maximum body depths of various sizes of prey fish, including bluegill, yellow perch, and black bullhead, were also measured using calipers. These head width and body depth versus total length relationships for the respective species are shown in Figures 4-7. Head widths of the predatory fish are strongly correlated to their throat width and the

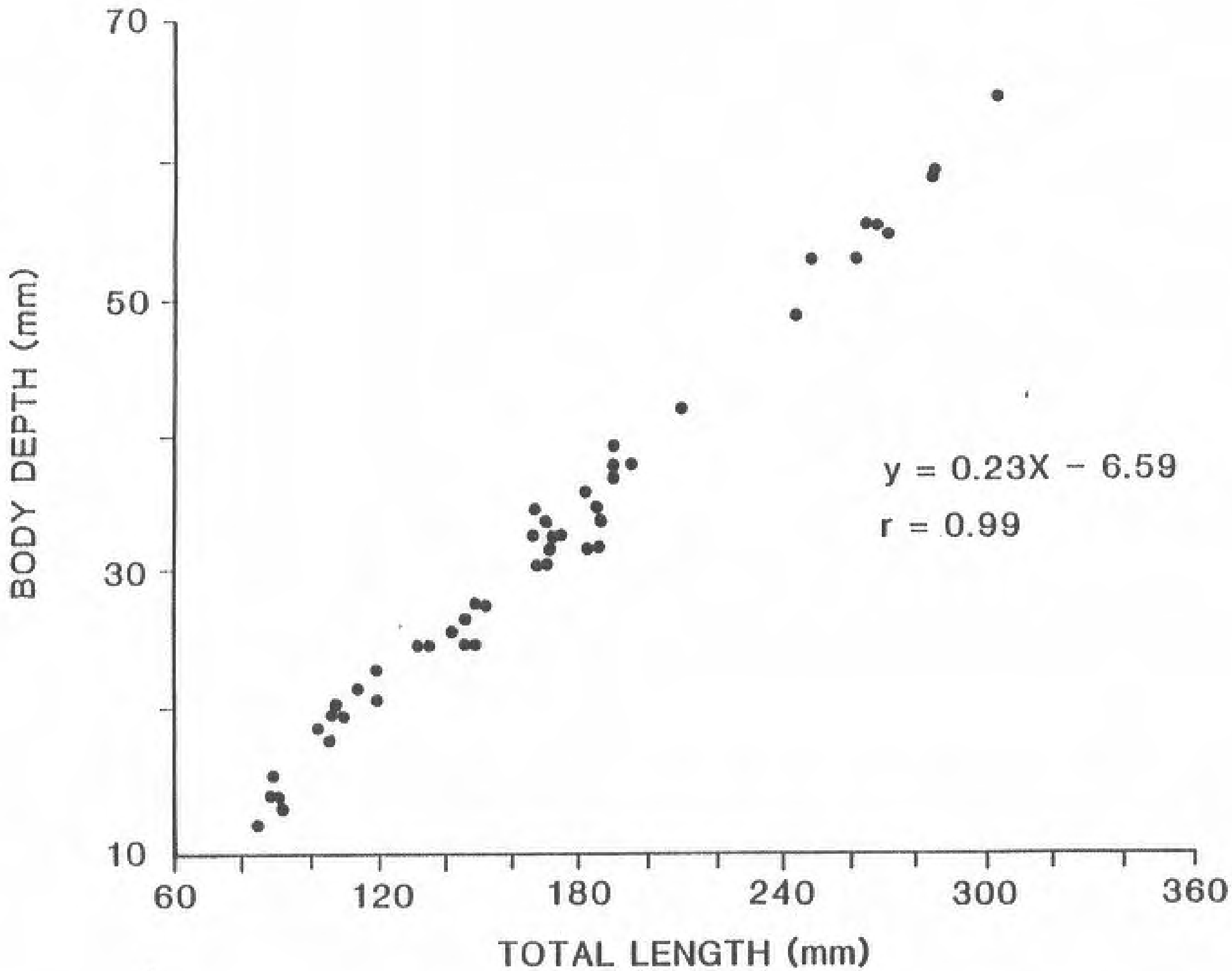

Figure 4. Relationship between the body depth and total length of yellow perch in East Lake Eureka, South Dakota.

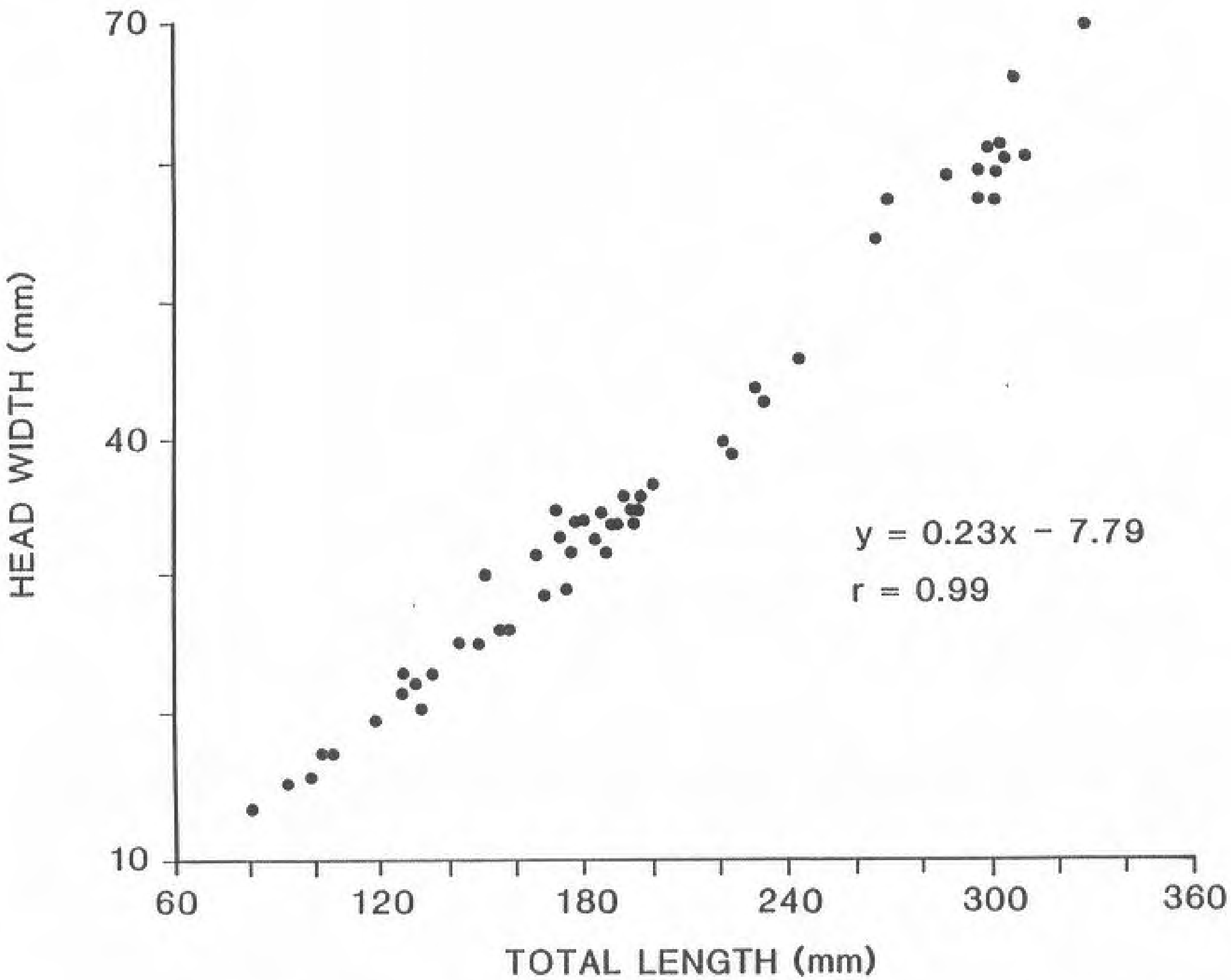

Figure 5. Relationship between the head width and total length of black bullheads in East Lake Eureka, South Dakota.

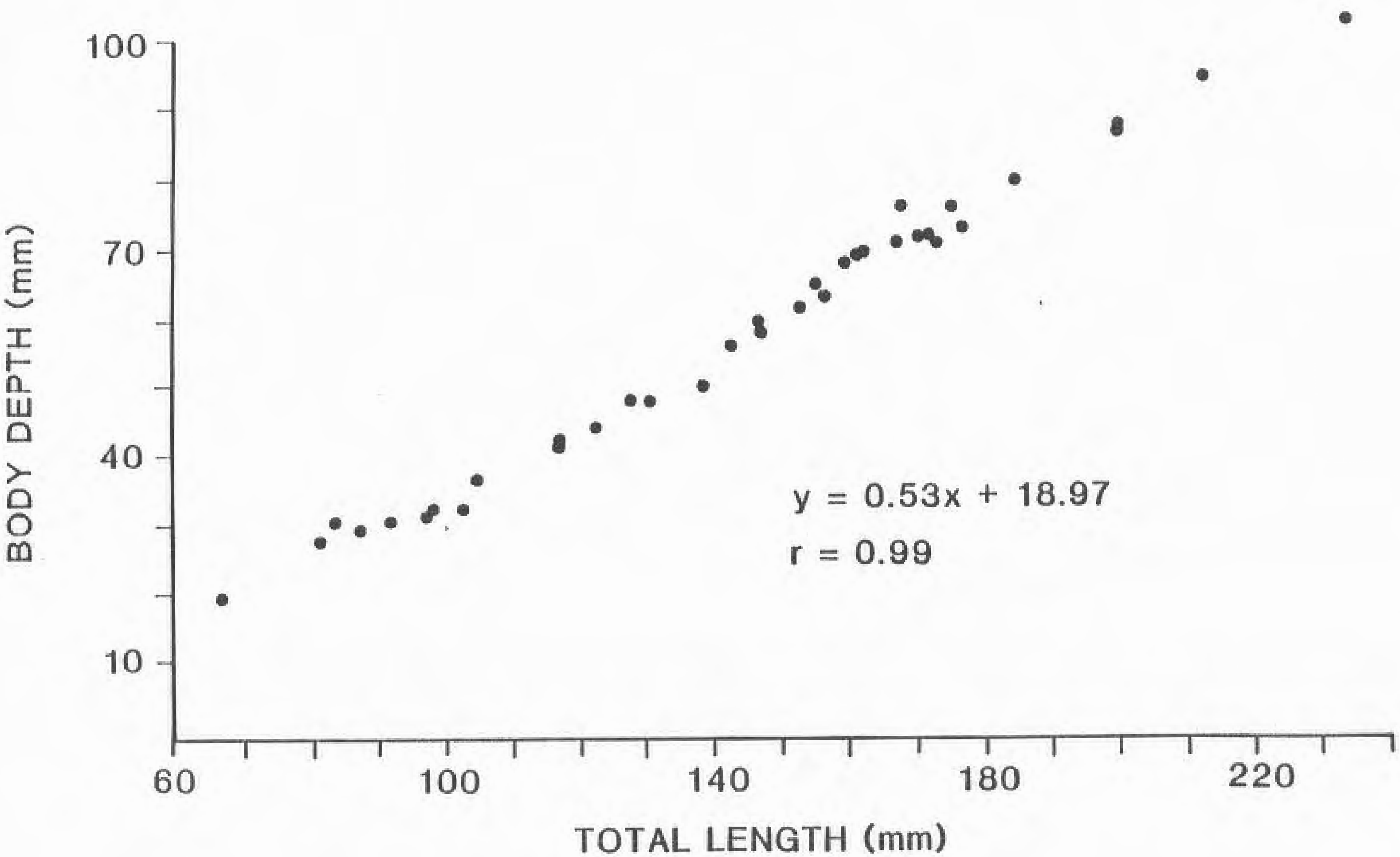

Figure 6. Relationship between the body depth and total length of bluegills in East Lake Eureka, South Dakota.

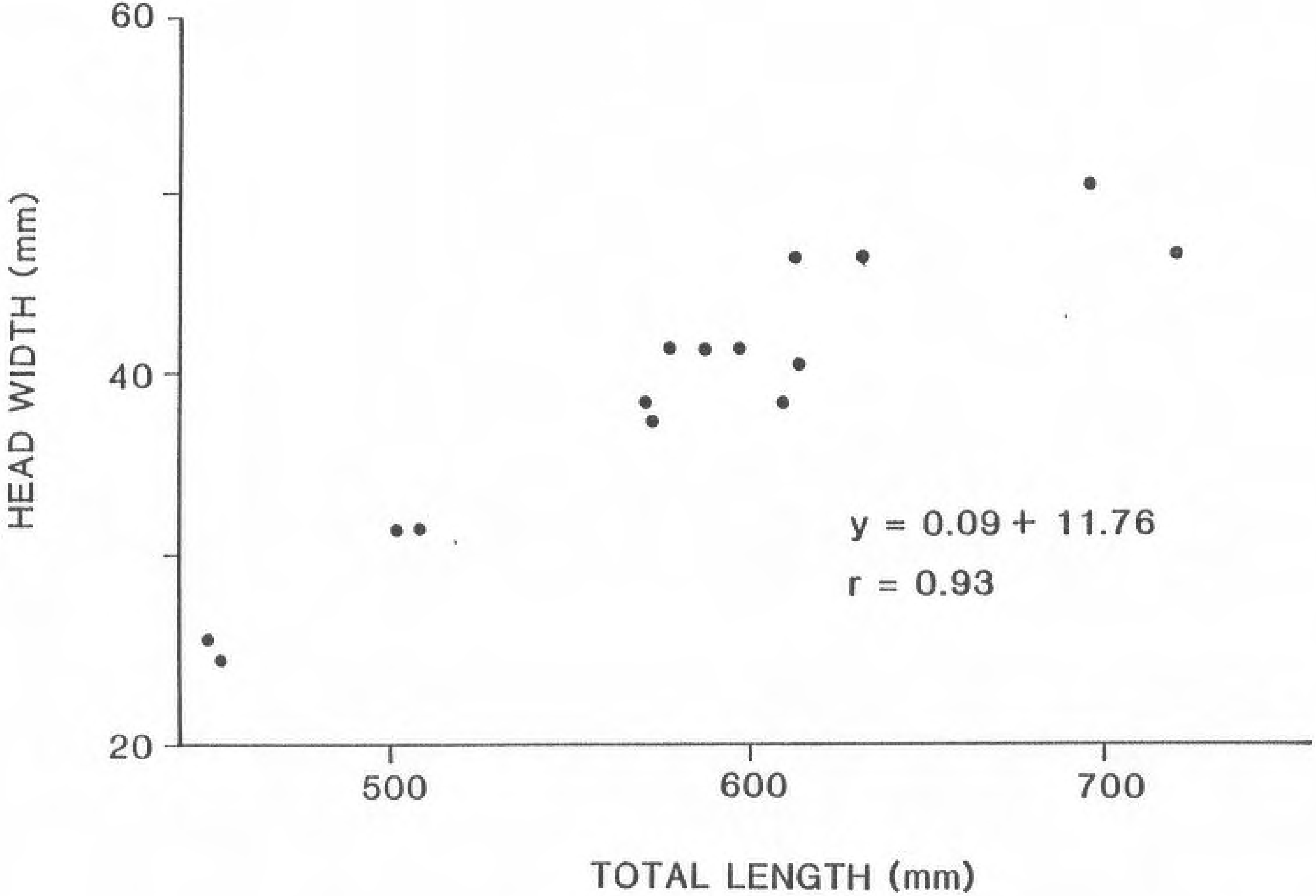

Figure 7. Relationship between the head width and total length of northern pike in East Lake Eureka, South Dakota.

maximum size of food item that can be swallowed (Lawrence 1958). Therefore, the relationships in Figures 4-7 were used to determine the sizes of prey fish that predatory fish could ingest. Then, by calculating biomass estimates for various size classes of prey and predatory fish, the predator/prey relationship in East Lake Eureka was evaluated using the available prey/predator (AP/P) ratio suggested by Jenkins and Morais (1978).

Population estimates of the most abundant fish species in East Lake Eureka were calculated from mark/recapture data. Catch per unit effort was calculated for the species captured by inshore beach seining. Population estimates for East Lake Eureka were calculated using the Schumacher and Eschmeyer formula (Ricker 1975) for multiple sampling events and recaptures. Size structure of the most abundant species in East Lake Eureka and Prior Lake was quantified by calculating Proportional Stock Density (PSD) (Anderson 1980) using the equation:

$$PSD = \text{number of fish} \geq QL \;/\; \text{number of fish} \geq SL \times 100$$

where quality length (QL) and stock length (SL) are minimum lengths established for each species by Gabelhouse (1984). Condition of the most abundant fish species in East Lake Eureka and Prior Lake was determined by calculating ponderal indices. Relative weight (W_r) (Anderson 1980) is a comparison of the actual weight of a fish to a calculated standard weight. Relative weight is calculated from the equation:

$$W_r = (W/W_s) \times 100$$

where:

W_r = relative weight,

W = actual weight, and

W_s = standard weight corresponding to that length of fish, calculated from a formula.

Reliable standard weight equations were available only for largemouth bass, bluegill (Anderson and Gutreuter 1983), and just recently, northern pike (D.W. Willis, South Dakota State University, personal communication). Therefore, for the other species, a condition factor (K) was calculated (Anderson and Gutreuter 1983) as follows:

$$K = W / L^3 \times 100{,}000$$

where:

K = condition factor,

W = weight of fish in grams, and

L = total length of fish in millimeters.

Condition factors (K) vary for different species and size classes of fish; therefore, K-values can only be compared among fish of similar lengths, within a single species.

Scale and spine samples were used to determine the age of the fish (Jearld 1983). Spines of black bullheads were sectioned into thin slices which were then viewed with a microfiche reader. This allowed the determination of growth rates for black bullheads based upon the mean total length (TL) for each age group of fish. For other species, impressions of scales were made onto acetate slides using a roller press. Slides were then viewed on a microfiche reader to determine age, and distances between annuli were measured. These measurements were then used to back-calculate the size of fish at previous annuli (Bagenal and Tesch 1978) using the formula:

$$ln - a = Sn/S\ (l-a)$$

where:

ln = length at annulus n,

l = total body length,

Sn = scale length from focus to annulus n,

S = total scale length,

a = correction factor.

Standard correction factors (a) used were recommended by Carlander (1982). Once lengths at previous ages were determined, these were used to calculate incremental growth rates which were analyzed by comparing the incremental growth of the fish to its initial length in its last completed year of growth (Gabelhouse 1987).

Because of the short duration of this study, most of the data collected simply are descriptive of the pre-treatment conditions (prior to grass carp introduction and subsequent aquatic vegetation removal). Fish population variables were calculated as described for East Lake Eureka only for 1986; any real analysis of the effect of grass carp introduction and subsequent aquatic vegetation removal must await future data collections and comparisons between them and this study. This also holds true for the data collected from Prior Lake, due both to the short duration of this study, and due to the winterkill in 1986. Thus, fish population parameters from Prior Lake were calculated only for 1987.

RESULTS AND DISCUSSION

Aquatic Vegetation

Aquatic vegetation coverage in Prior Lake was reduced from over 60% before grass carp introduction to 2% in the summer of 1987 (Figure 8); this reduction in vegetation coverage was significant ($P<0.005$). Aquatic vegetation height was also significantly lower ($P<0.005$) after the

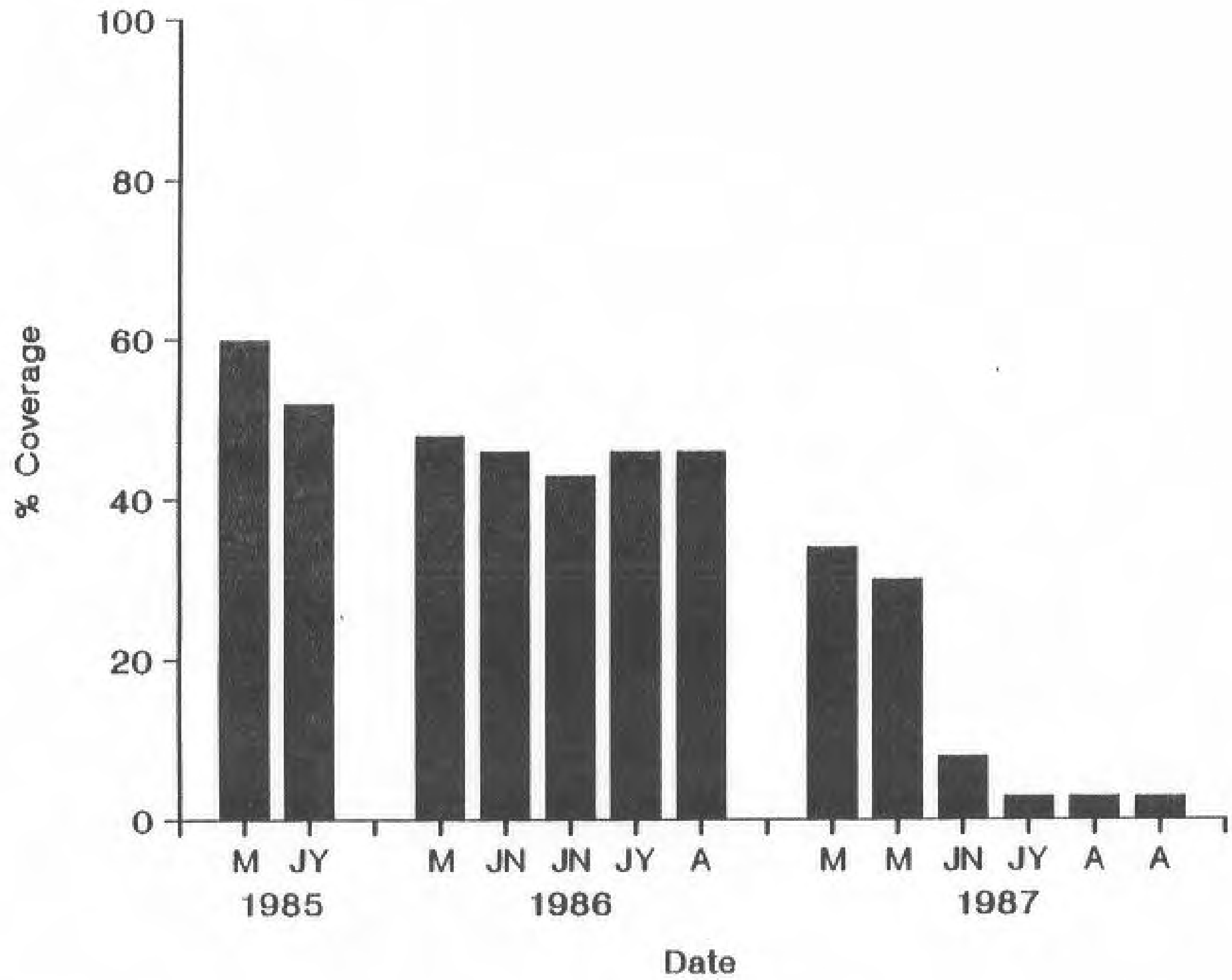

Figure 8. Percent of the bottom covered by aquatic vegetation along transects in Prior Lake, South Dakota, during the summers of 1985-1987 (M=May, JN=June, JY=July, A=August). Grass carp were introduced in June, 1985.

coverage decreased (Figure 9). Aquatic vegetation levels were reduced along all transects having weed growth (Appendices 1 and 2). The height of aquatic vegetation in the water column in 1986 did suggest some partial vegetation reduction (Figure 8); however, the declining aquatic vegetation height in the late summer of 1986 may have simply reflected a normal die-off of vegetation. Aquatic vegetation height never did begin to increase in 1987.

Total or near total eradication of aquatic vegetation by grass carp has been observed in many cases. Ware and Gasaway (1977), and Mitzner (1978) both provided examples of complete aquatic vegetation removal by grass carp in small lakes or reservoirs. Apparently this "all-or-none" pattern of aquatic vegetation removal is typical with grass carp, because no instances of partial aquatic vegetation reduction by grass carp are noted by other researchers.

At East Lake Eureka (Figures 10 and 11) no aquatic vegetation reduction was evident over the two-year period. Coverage levels remained about 65% with a mean of about 50% of the water column occupied by vegetation throughout the study period. No aquatic vegetation reduction was noted in East Lake Eureka along any transects (Appendices 3 and 4).

At optimum temperatures (20-26°C, 68-79°F), 2.7-5.9 kg (6-13 lb) triploid grass carp will consume 75% of their body weight per day in aquatic vegetation (Clugston and Shireman 1987); therefore, a higher biomass of grass carp will

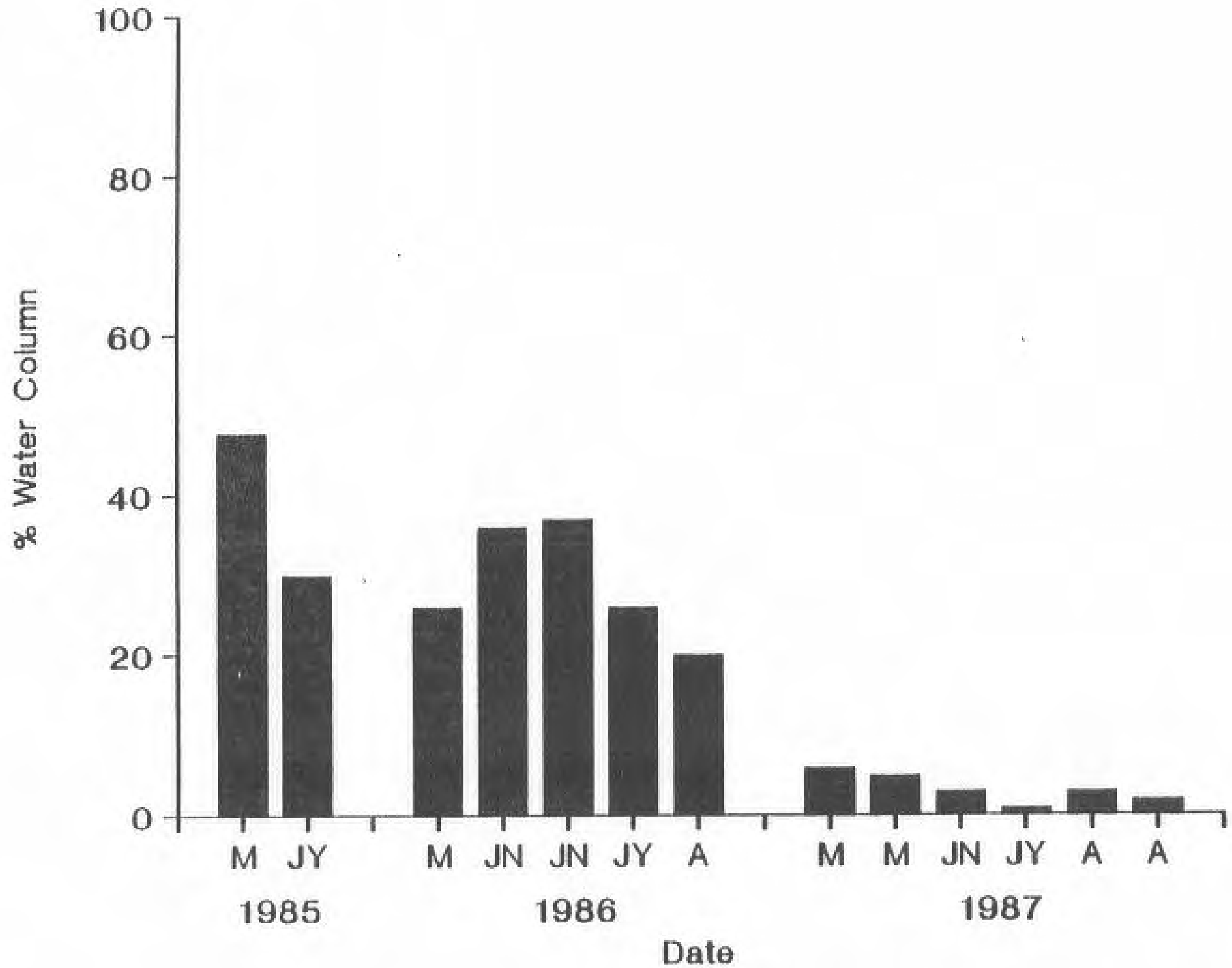

Figure 9. Percent of the water column occupied by aquatic vegetation along transects in Prior Lake, South Dakota, during the summers of 1985-1987 (M=May, JN=June, JY=July, A=August). Grass carp were introduced in June, 1985.

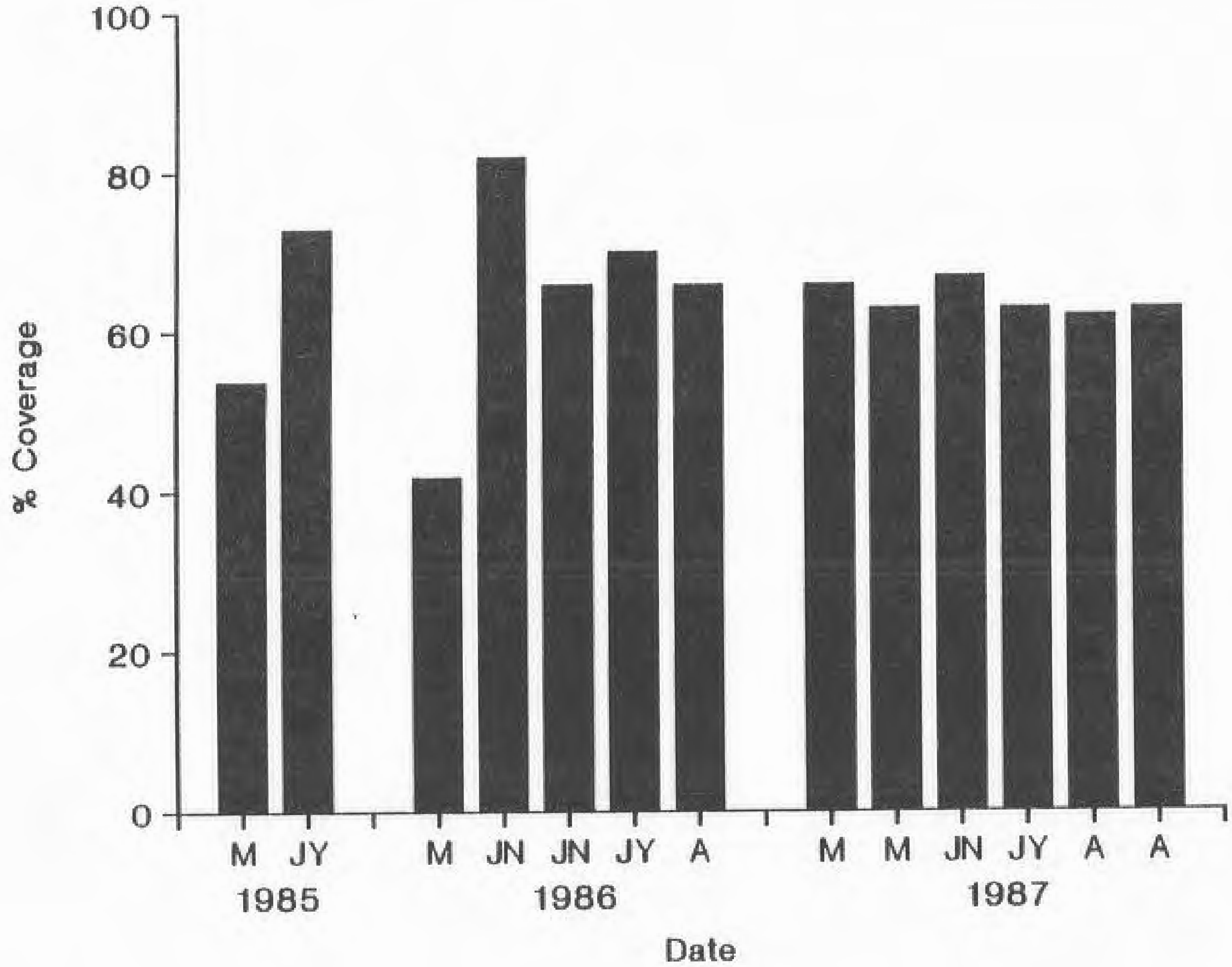

Figure 10. Percent of the bottom covered by aquatic vegetation along transects in East Lake Eureka, South Dakota, during the summers of 1985-1987 (M=May, JN=June, JY=July, A=August). Grass carp were introduced in June, 1985.

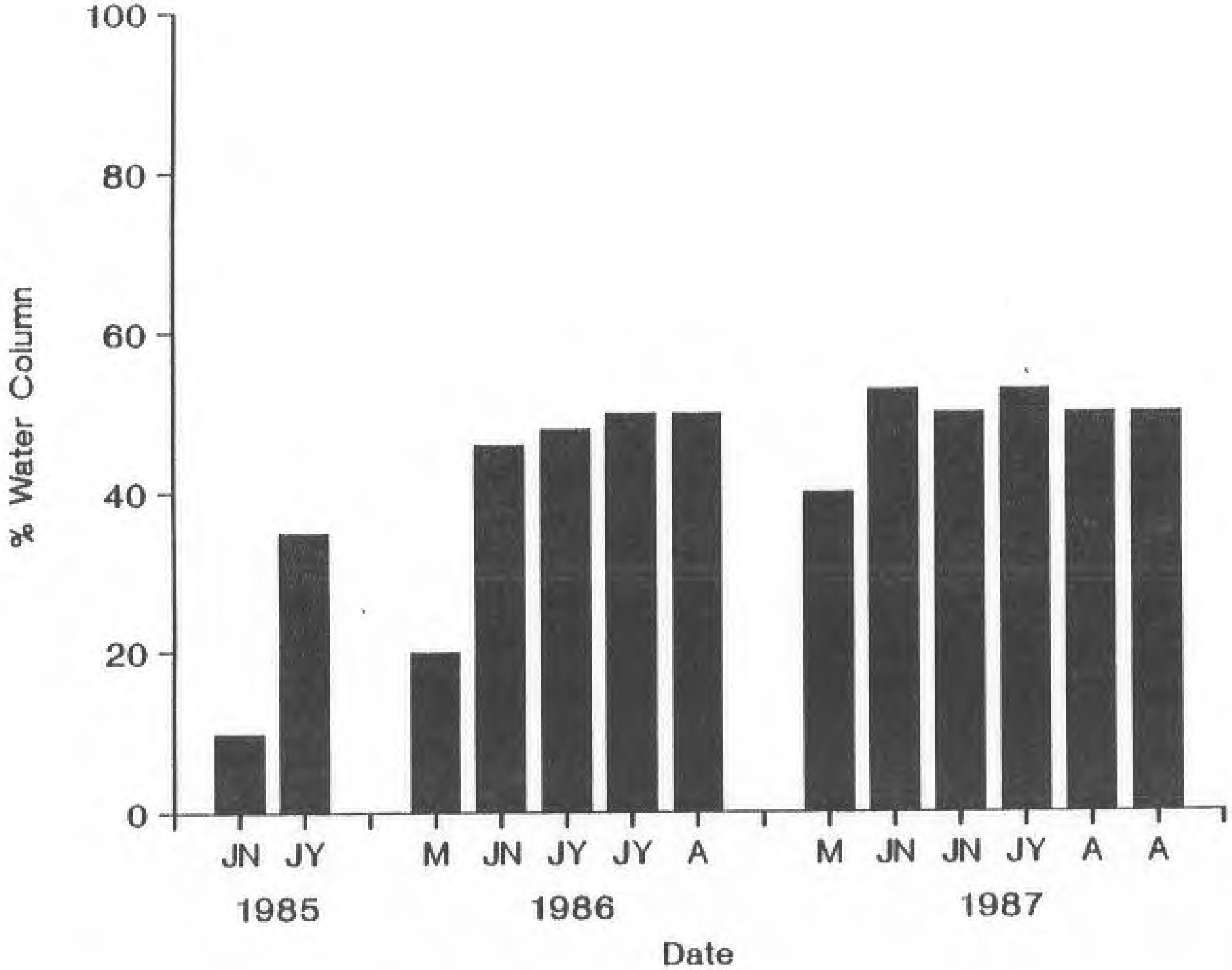

Figure 11. Percent of the water column occupied by aquatic vegetation along transects in East Lake Eureka during the summers of 1985-1987 (M=May, JN=June, JY=July, A=August). Grass carp were introduced in June, 1985.

logically consume more aquatic vegetation. A higher biomass of grass carp can be achieved through higher stocking densities and/or the fish growing to a larger size. Eventually, grass carp biomass must reach some threshold level where their consumption exceeds the aquatic vegetation production. Then, instead of simple aquatic vegetation control, it appears that grass carp biomass and total consumption continues to increase, eradicating all aquatic vegetation.

In East Lake Eureka, grass carp biomass apparently has not reached the level necessary to control aquatic vegetation. However, East Lake Eureka was stocked with 61 grass carp/hectare compared to 49 grass carp/hectare in Prior Lake, so an additional factor must be influencing the reduction of aquatic vegetation. Lake Eureka is located farther north than Prior Lake; therefore, the period of optimum feeding temperatures for grass carp was shorter as was the growing season. Aquatic vegetation grows rapidly in the spring and summer to peak levels, and with this quick growth of aquatic vegetation and the short period of optimum feeding temperatures, the biomass level of grass carp in South Dakota may need to be even higher than in other waters. The 61 grass carp/hectare stocking density would be considered quite high compared to those recommended for Illinois waters (Wiley et al. 1987). However, the grass carp computer model developed by Swanson and Bergersen

(1986) for cold-water fisheries would recommend an even higher stocking rate (76 grass carp/hectare). Perhaps one more year of growth for the grass carp in East Lake Eureka will increase their biomass to a level necessary for vegetation reduction.

The predominant weed type in both Prior Lake and East Lake Eureka was Chara. Chara spp. are among the plants most preferred by grass carp (Cassani and Caton 1983; Harberg and Modde 1985). However, one study (Prowse 1971) reported that Chara flexilis was "gritty" with calcium carbonate crystals, had an unpleasant odor and was eaten as "a last resort" by grass carp. As was noted earlier, the conductivity of East Lake Eureka was exceptionally high, and perhaps this extremely hard water made the Chara less palatable to the grass carp. This might necessitate greater grass carp biomass to control the aquatic vegetation.

Secchi disk transparency was significantly lower ($P<0.005$) in Prior Lake after aquatic vegetation was reduced (Figure 12). Transparencies remained quite high in East Lake Eureka throughout the study period (Figure 13). Increased turbidity has been commonly reported following vegetation reduction by grass carp (Lembi et al. 1978; Wiley and Gorden 1984). Increased turbidity could be attributed to increased phytoplankton density following aquatic macrophyte reduction. This was reported by Wiley and Gorden (1984), and in Prior Lake was evident in the green-colored

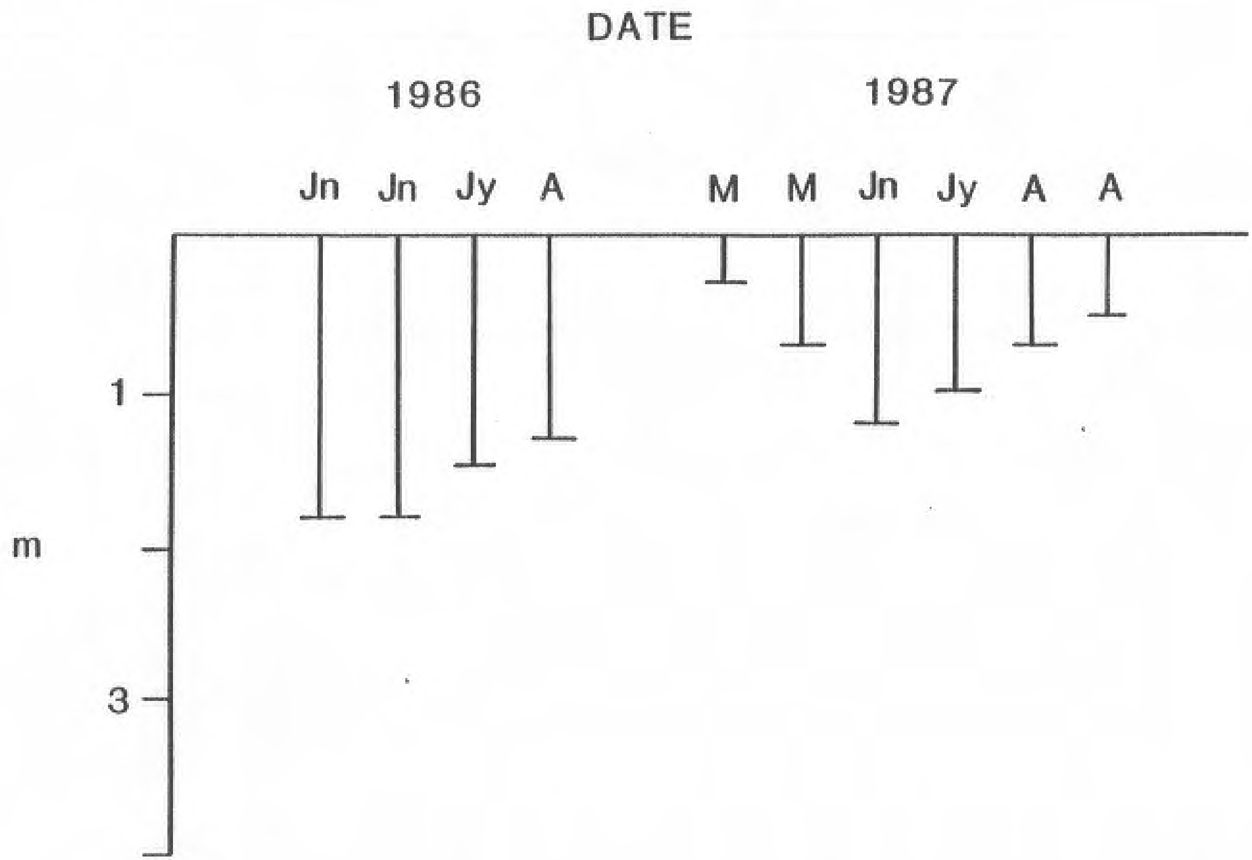

Figure 12. Secchi disk transparencies at Prior Lake, South Dakota, duri
summers of 1986 and 1987 (M=May, JN=June, JY=July, A=August)

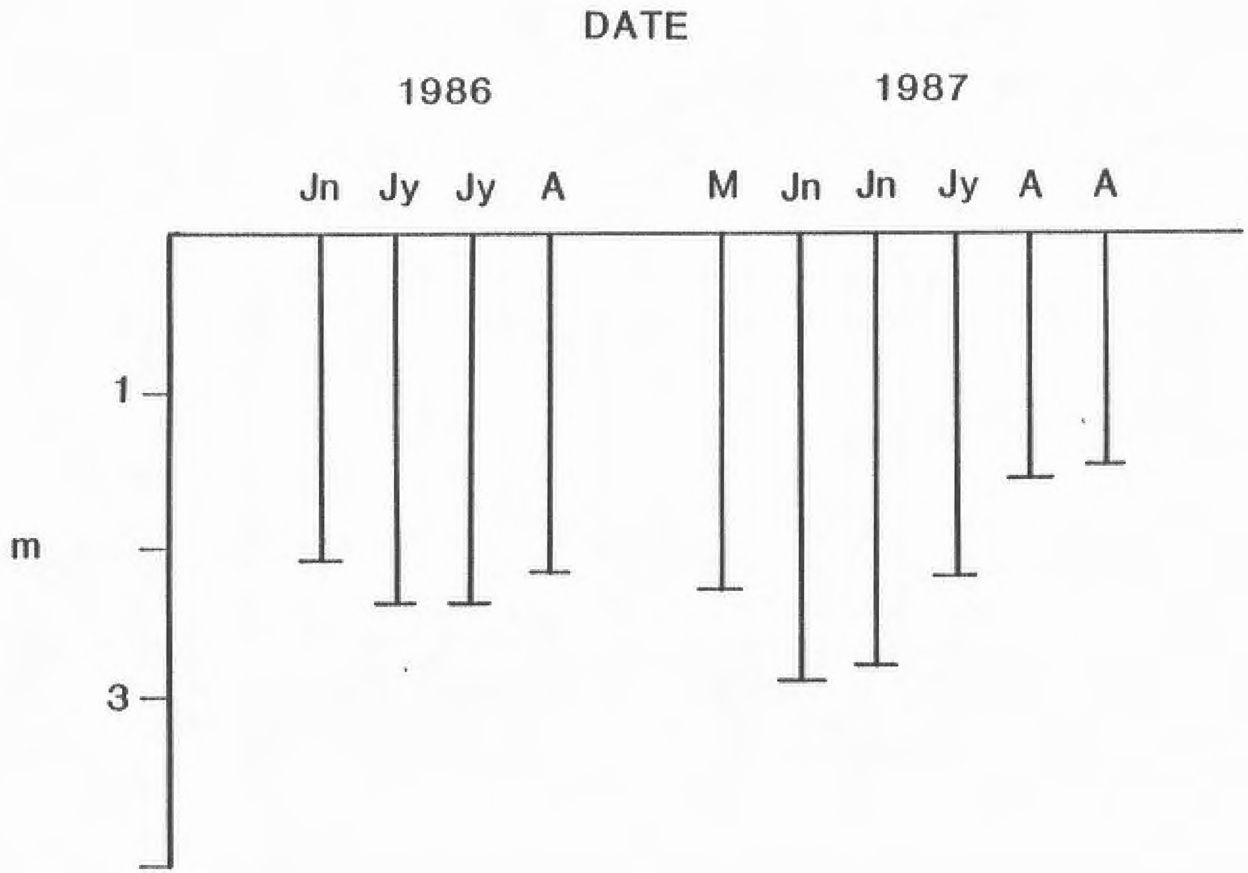

Figure 13. Secchi disk transparencies at East Lake Eureka, South Dakota, during the summers of 1986 and 1987 (M=May, JN=June, JY=July, A=August).

water. However, neither Lembi et al. (1978) nor Mitzner (1978) observed any increase in phytoplankton, and Lembi et al. (1978) attributed the increased turbidity to increased sediment in the water.

Fish

A partial winterkill was observed on Prior Lake in the early spring of 1986. Assuming this would confuse any of the effects of grass carp introduction and aquatic vegetation reduction on the existing fish populations, fisheries sampling was reduced on Prior Lake. Some limited sampling was conducted in May, 1987, producing a data set that is representative of the fish populations in Prior Lake immediately after aquatic vegetation removal. This data set might be considered pre-treatment, assuming insufficient time had elapsed for any effects of the vegetation removal to become evident in the fish populations. Bluegill and largemouth bass were the dominant species (Table 1).

Bluegill were the most abundant fish in both the trap net and electrofishing catches in Prior Lake. In 1987 a total of 527 bluegills were sampled, and the size structure of the fish sampled by trap netting is depicted in Figure 14. Prior Lake bluegills were comprised of two size classes. Only two bluegills greater than 150 mm (quality length) were sampled, and therefore the PSD was only 1. This low PSD value would indicate an over-populated,

Table 1. Numbers of fish captured with trap nets and by electrofishing in Prior Lake, South Dakota, in 1987.

Species	Total catch		
	Trap nets	Electrofishing	Total
Bluegill	397	270	667
Largemouth bass	0	24	24
Green sunfish	1	11	12
Black crappie	9	0	9
Black bullhead	2	0	2

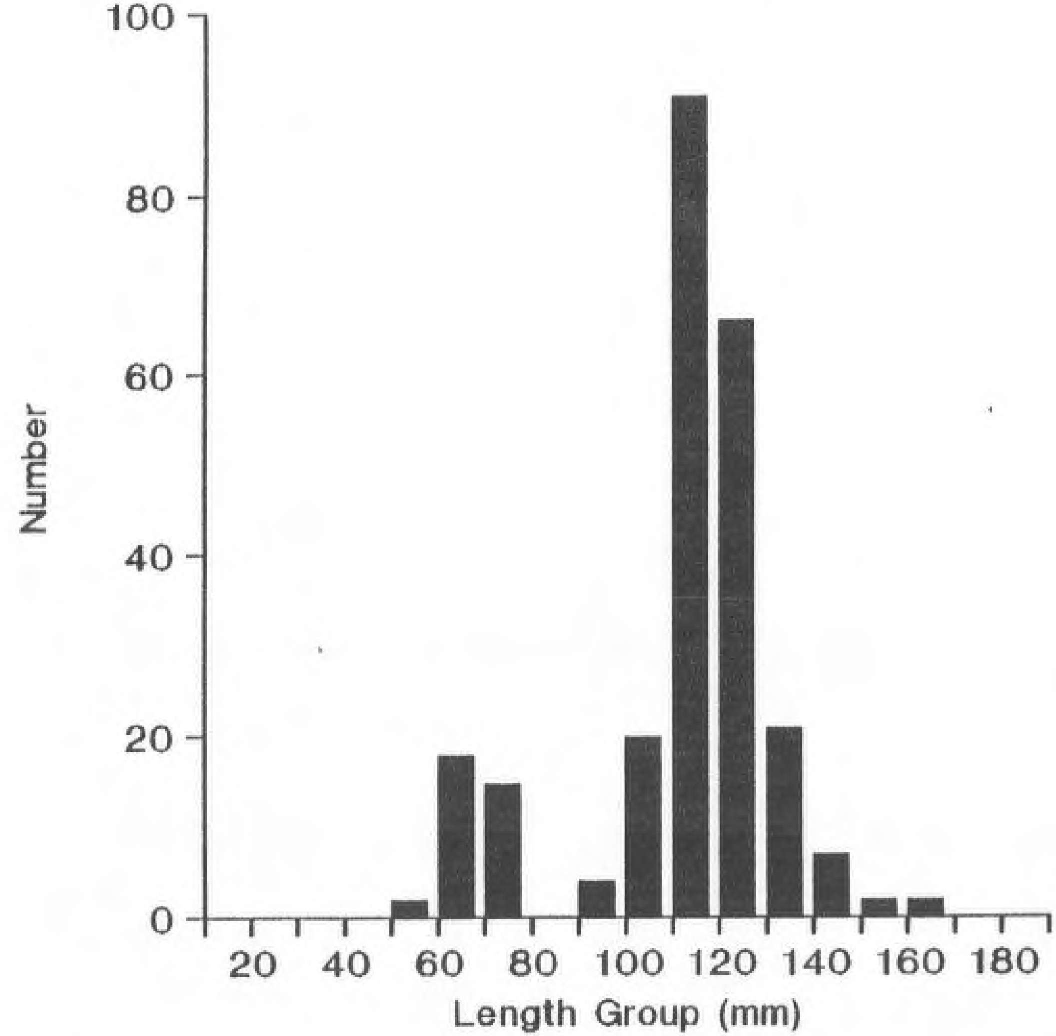

Figure 14. Length-frequency distribution of bluegills collected with trap nets from Prior Lake, South Dakota, in 1987.

slow-growing population (Anderson 1980): however, the mean W_r for those bluegills sampled was 109 which indicated fish in good condition. Scale analysis showed that the bluegills in Prior Lake were relatively slow-growing with the 110-130 mm fish being age 3. Carlander (1977) reported an average of 149 mm at age 3 for Iowa waters. The winterkill in the early spring of 1986 likely explains the discrepancy in these data for Prior Lake bluegills in 1987. Size structure (Figure 14) and the slow growth rates reflected the bluegill population status before the winterkill; thus these variables indicated a stunted, slow-growing population. However, the high W_r of 109 seemed contradictory. The winterkill apparently reduced competition among bluegills and thus their relative weights were high. If the bluegill population expands and again becomes stunted, W_r values likely would again decline.

A total of 24 largemouth bass were captured from Prior Lake in 60 min of electrofishing. All but one of these fish were under 300 mm (TL), and the PSD was only 7. The W_r for these bass was 112, again indicating healthy fish. Linear regression of the initial length at the last annulus plotted as a function of the growth increment (Appendix 7) had a correlation coefficient (r) of -0.58 ($P<0.02$) reflecting the variability of the plotted points (Figure 15). Reduced variability in the growth increments of the larger, older fish does allow one to conclude that the growth rates are

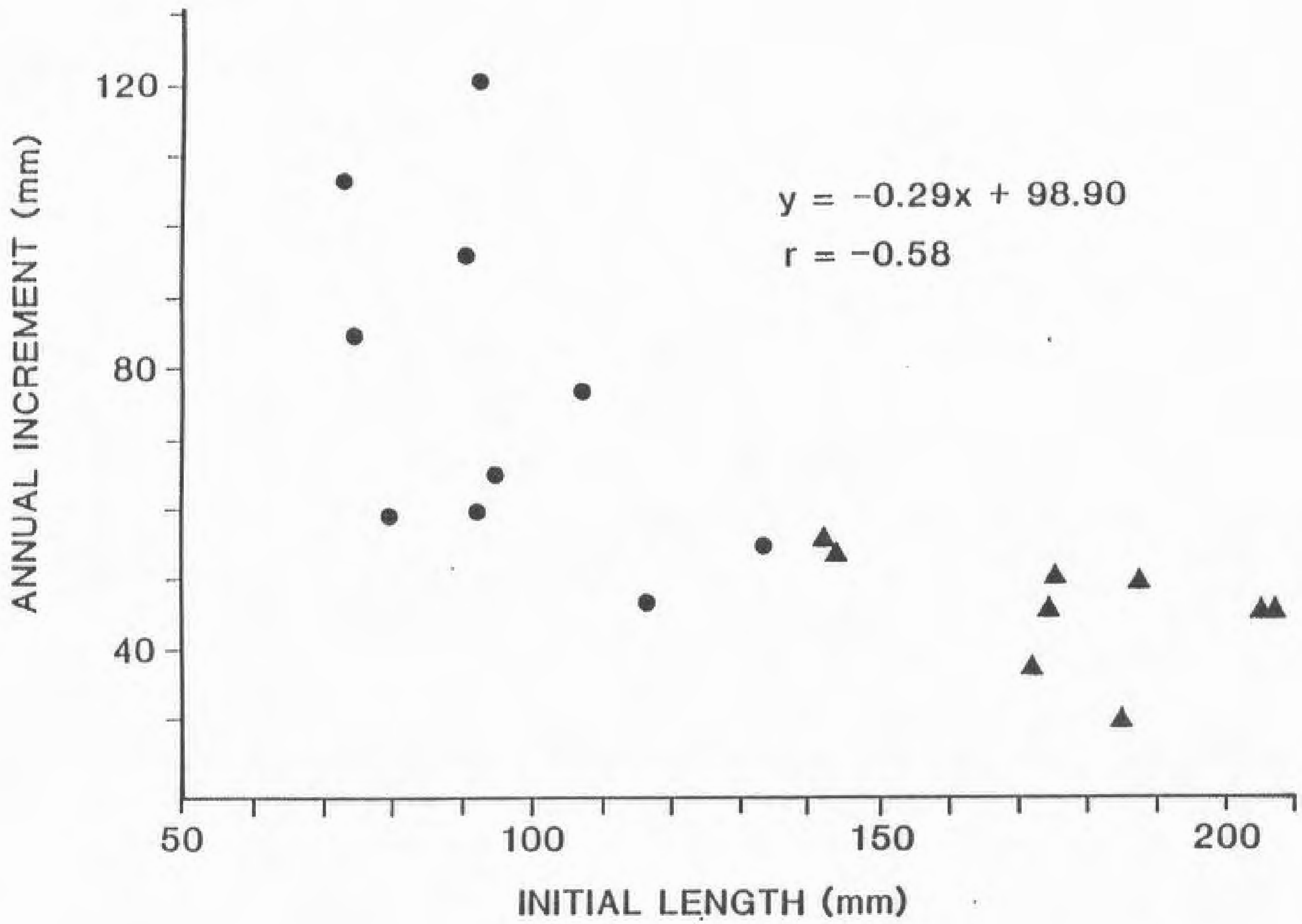

Figure 15. Initial length in last completed year of growth, versus annual growth increment for age-2 (●), and -3 (▲) largemouth bass from Prior Lake, South Dakota.

relatively slow. Carlander (1977) reported the average TL for Minnesota and South Dakota largemouth bass was 315 mm for age-3 fish. Age-3 largemouth bass in Prior Lake had a mean TL of only 252 mm.

Being located in the center of town, Prior Lake had the added factor of heavy fishing pressure. From experience, it was rare to arrive at Prior Lake at any time and not see at least three or four young fishermen on the banks. Largemouth bass probably received most of the fishing pressure and any of quality length (300 mm TL) are probably harvested. The overpopulation of bluegills as well as the size structure of the largemouth bass population would tend to indicate that this is true. The elimination of aquatic vegetation in Prior Lake could compound this problem as the largemouth bass become even more vulnerable to angling.

Much more effort was put forth in sampling the fish populations in East Lake Eureka. This was done in both 1986 and 1987; here the 1986 data will be discussed as a pre-treatment data set prior to aquatic vegetation reduction.

Population and biomass estimates for the most abundant fish species in East Lake Eureka are shown in Table 2. These standing stocks were comparatively high, when compared to data summarized by Carlander (1955), for all species except the bluegill, which were at an average level for lakes (but quite low compared to pond populations). Sample

Table 2. Population and biomass estimates for the most abundant fish species in East Lake Eureka, South Dakota, in 1986. The 95% confidence intervals are shown in parentheses.

Species	Fish/hectare	Kg/hectare
Black bullhead	772.1 (651.4-947.4)	88.3 (62.2-108.3)
Yellow perch	2,214.8 (1,651.9-3,358.0)	85.3 (63.7-129.5)
Bluegill	389.9 (294.1-578.0)	17.3 (13.1-25.2)
Northern pike	12.8 (4.9-23.7)	13.8 (5.1-25.2)

size for northern pike was small making the confidence intervals quite large.

Bluegill population size structure from the trap net sample is shown in Figure 16. The population was comprised mostly of individuals less than 150 mm long and this is reflected in a PSD of 11. However, in 1987 more effort was made in sampling the areas of dense weedy cover where most of the bluegills were observed, and a PSD of 34 was calculated from the 1987 trap net samples. Only 64 bluegills were captured in trap nets in 1987; their size structure is depicted in Figure 17. The bluegill population in East Lake Eureka was comprised of three size classes and age groups. Quality length (TL≥150 mm) bluegills probably were under-represented in the 1986 data. The mean W_r of 117 for East Lake Eureka bluegill also indicated a healthy population. Linear regression of incremental growth data (Appendix 8) from the analysis of bluegill scales is displayed in Figure 18. The wide scatter of points is reflected in the poor correlation coefficient (r) of -0.29 ($P<0.01$). By dividing the relationship shown in Figure 18 into a positive relationship between growth increments and initial lengths in the age-2 bluegills and a negative relationship between growth increments and initial lengths in the age-3 and -4 bluegills, correlation coefficients of $r = 0.73$ ($P<0.001$) and $r = -0.71$ ($P<0.001$), respectively, are obtained. These results are also quite similar to those

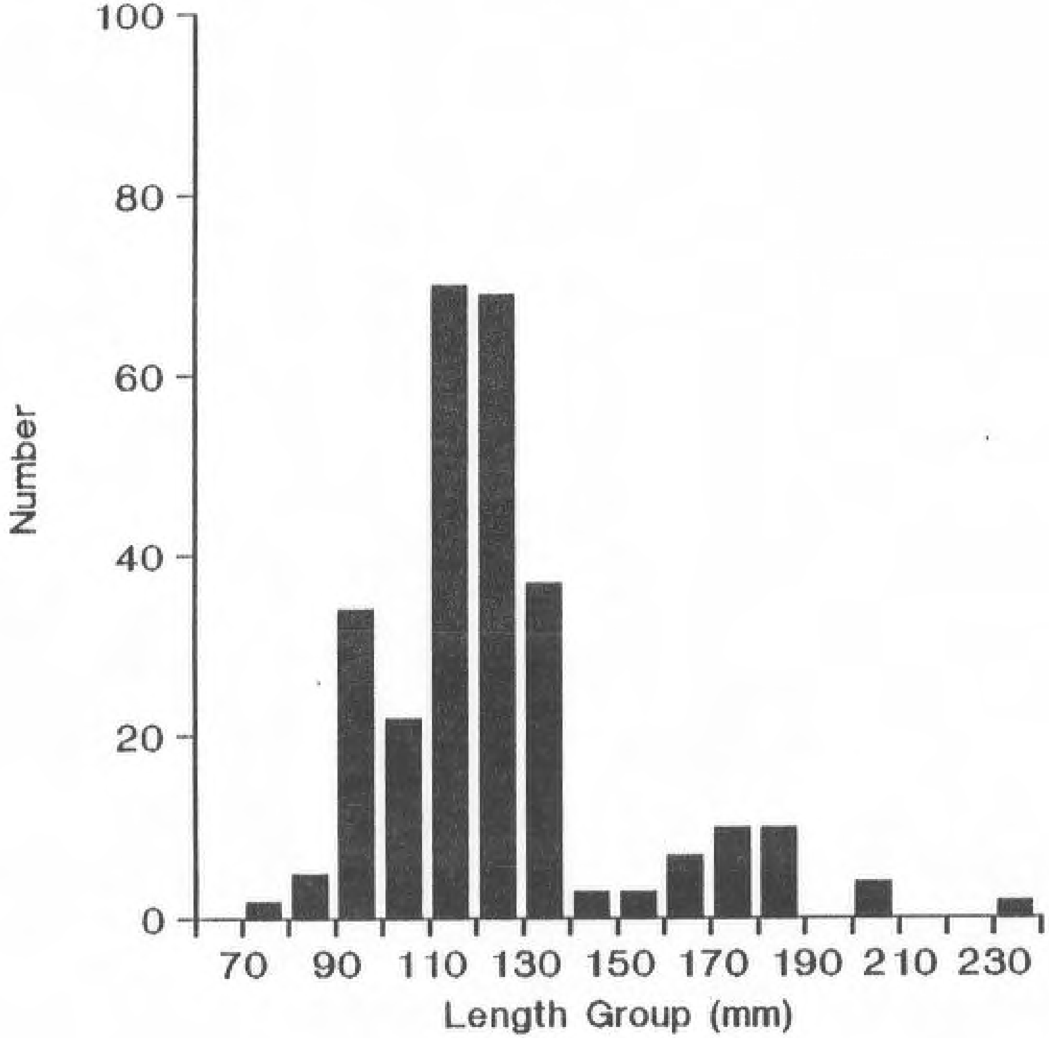

Figure 16. Length-frequency distribution of bluegills collected with trap nets from East Lake Eureka, South Dakota, in 1986.

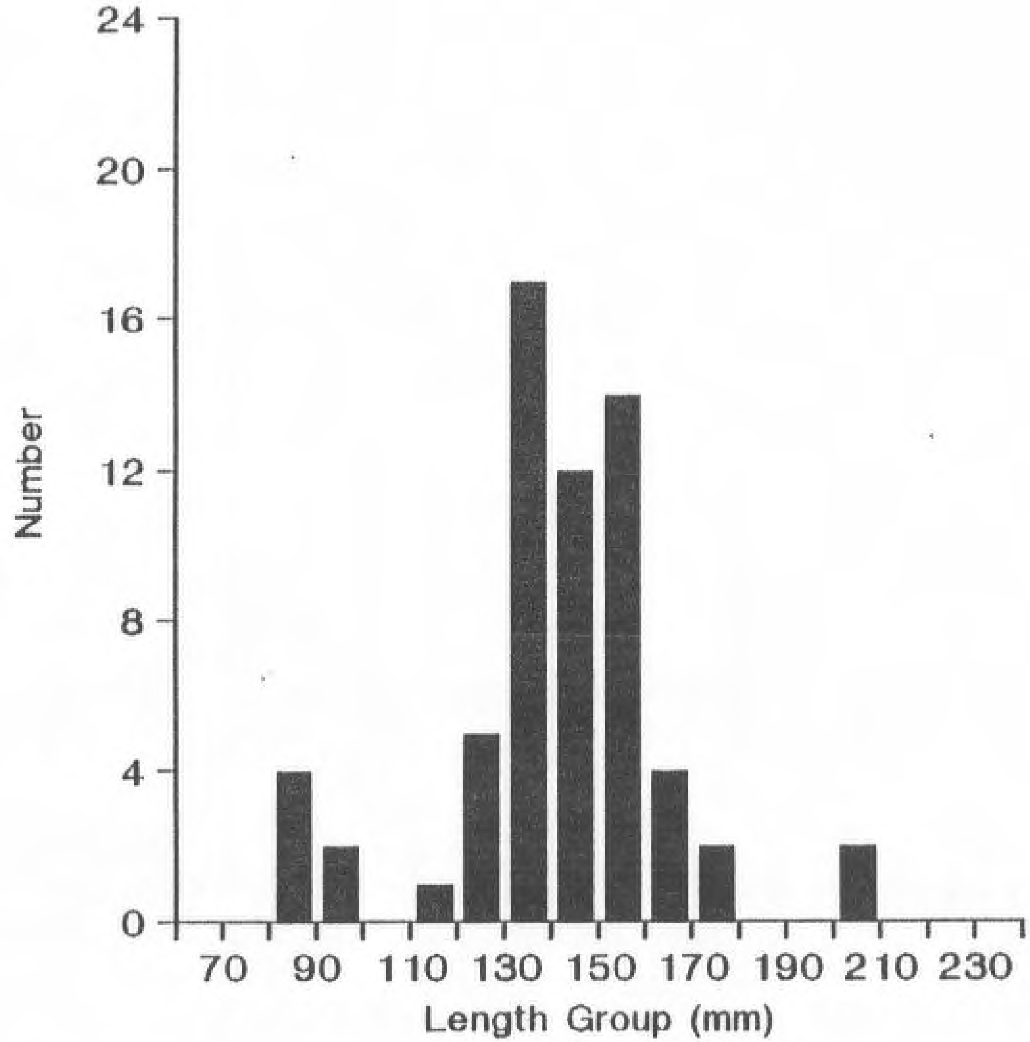

Figure 17. Length-frequency distribution of bluegills collected with trap nets from East Lake Eureka, South Dakota, in 1987.

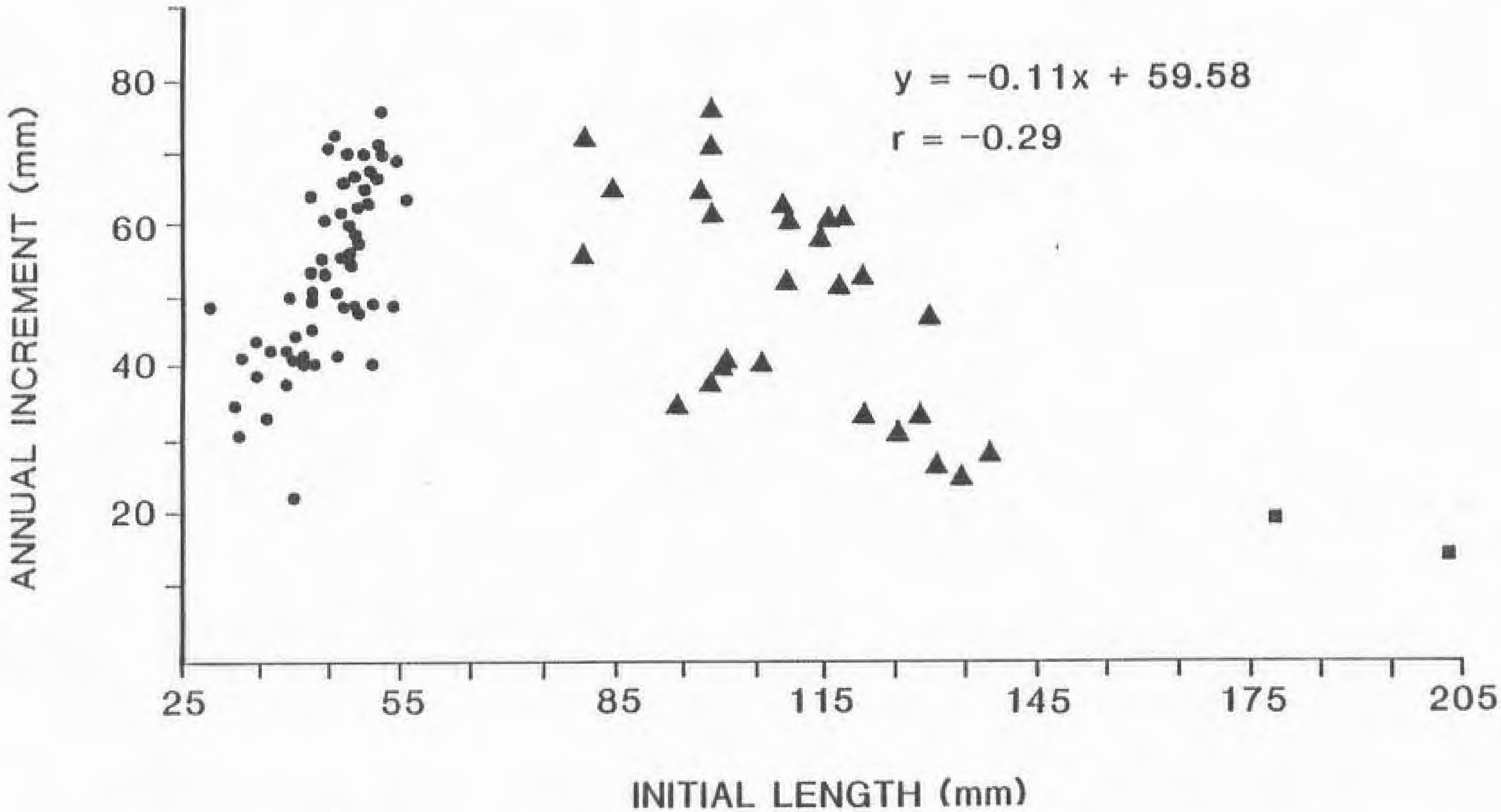

Figure 18. Initial length in last completed year of growth, versus annual growth increment for age-2 (●), -3 (▲), and -4 (■) bluegills from East Lake Eureka, South Dakota.

observed by Gabelhouse (1987) for bluegills in a Kansas pond. The larger, age-2 bluegills apparently are better competitors than the small, age-2 bluegills, and have faster growth rates. Then, the growth increments do decrease for the age-3 and -4, larger fish.

The black bullhead population in East Lake Eureka was comprised of two distinct length classes of fish (Figure 19), although each length class was comprised of more than one age group of bullheads (Table 3). Large numbers of bullheads were less than 230 mm TL (quality length) and the PSD was 8. Mean condition factor (K) for East Lake Eureka black bullheads was 1.58 which was relatively high compared to Iowa ponds, and Lewis and Clark and Francis Case Lakes in South Dakota (Carlander 1969). However, a higher condition factor (K=1.66) was reported for Lake Oahe black bullheads (Carlander 1969). The age-and-growth data in Table 3 are simply the length at capture for each age group of fish. Growth rates for East Lake Eureka black bullheads were relatively good compared to averages for North Dakota and Clear Lake, Iowa (Carlander 1969). The age-3 group of black bullheads was almost entirely lacking from the fish sampled; apparently recruitment of the 1983 year class was unsuccessful for some reason.

A high number of yellow perch were estimated to be in East Lake Eureka (Table 2), and most of these fish were 120-150 mm TL (Figure 20). A few quality length (TL$\geq$200 mm)

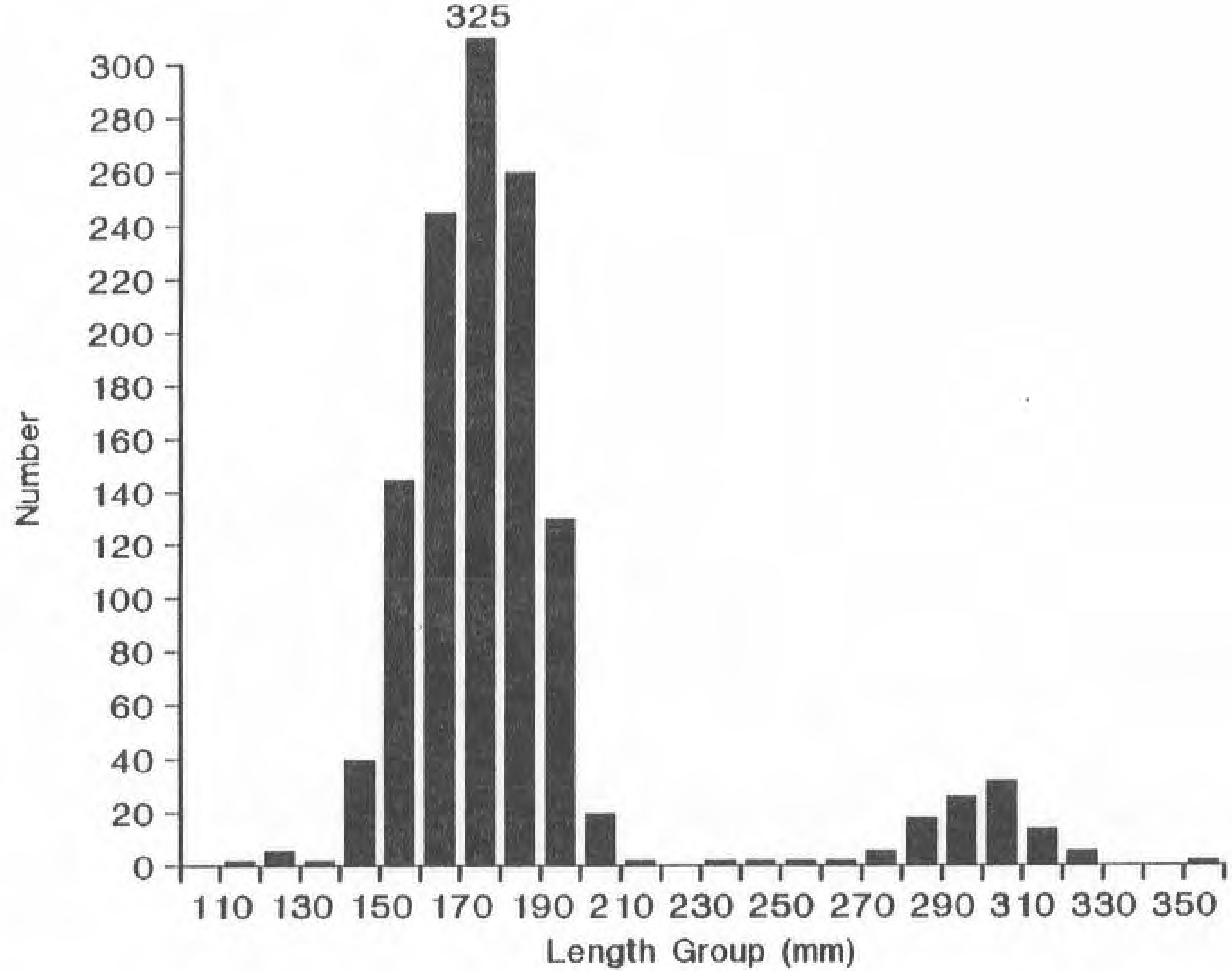

Figure 19. Length-frequency distribution of black bullheads collected with trap nets from East Lake Eureka, South Dakota, in 1986.

Table 3. Sample size (n), mean, minimum, and maximum lengths (mm) for each age group of black bullheads from East Lake Eureka, South Dakota.

Age	n	Mean	Minimum	Maximum
1	1	119	119	119
2	61	173	110	219
3	6	243	210	284
4	24	290	272	310
5	22	312	285	328
6	1	352	352	352

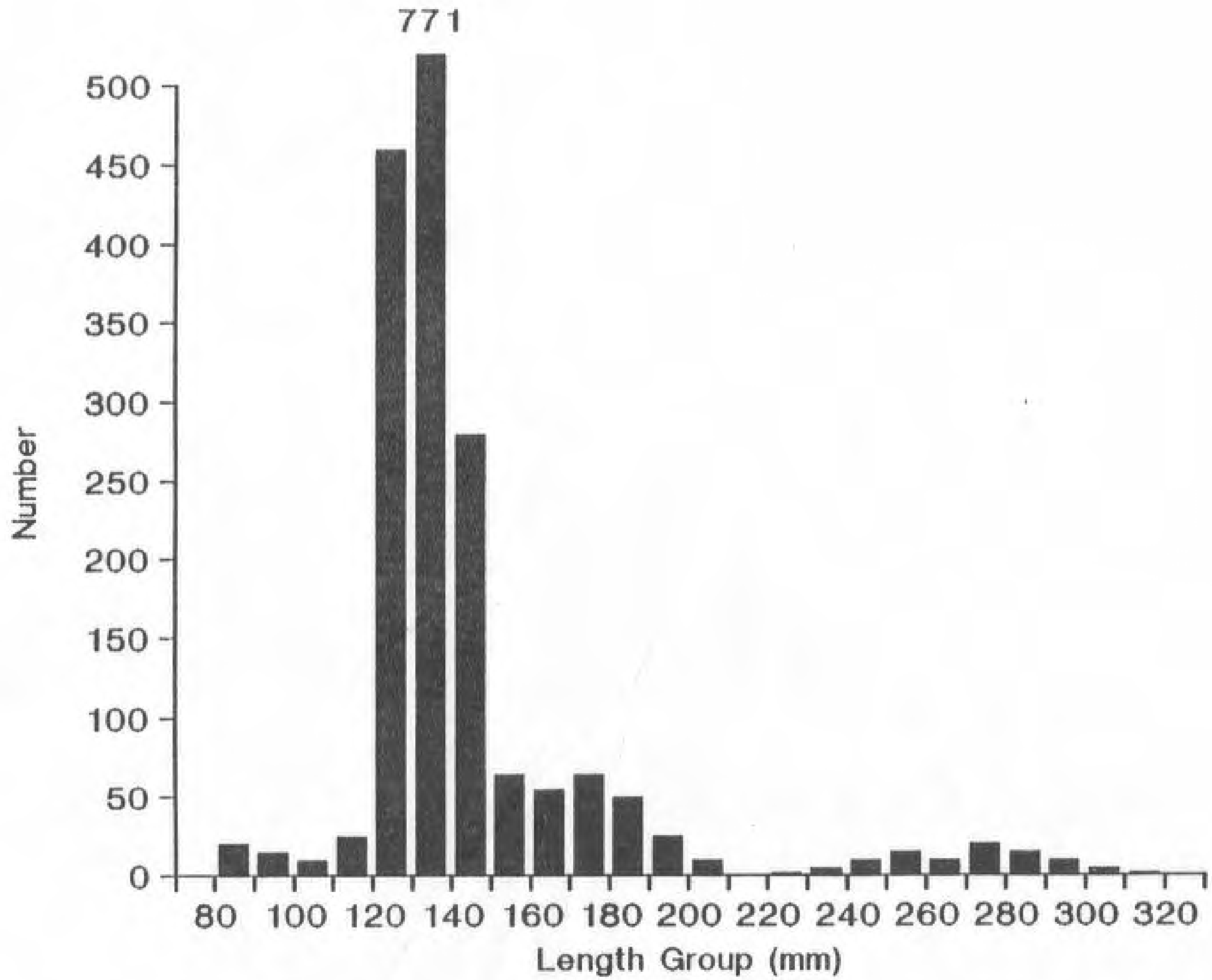

Figure 20. Length-frequency distribution of yellow perch collected with trap nets from East Lake Eureka, South Dakota, in 1986.

yellow perch were captured, but because of the high numbers of smaller fish the PSD was only 5. The mean condition factor (K) for East Lake Eureka yellow perch was 1.14. This condition factor was low compared to Iowa and Minnesota yellow perch which had K-values from 1.80 to 2.37 (Carlander 1953). Yellow perch initial length was highly correlated with growth increment ($r=0.963$, $P<0.001$) (Appendix 9, Figure 21). These growth rates are slow compared to yellow perch in Iowa and Minnesota lakes, especially for the smaller fish (Carlander 1953). The length-frequency distribution (Figure 20) and aging of yellow perch scales shows a pattern similar to that of the black bullhead; the 1983 year class was small. Additionally, the 1982 year class (age 4) was almost nonexistent for yellow perch; age-5 fish were actually more abundant than age-4 fish.

Few northern pike (n=20) were captured from East Lake Eureka in 1986, and only one fish was recaptured. Because of this, the confidence intervals for the northern pike population and standing stock are quite broad (Table 2), but similar results were obtained in 1987 when 16 northern pike were captured and 1 was recaptured. The 1986 results suggested a relatively high population of northern pike compared to other lakes and impoundments (Willis et al. 1984). The PSD value for this northern pike population was 53 while the mean W_r was 94. The slightly low W_r could be attributed to the post-spawn condition of the fish when they

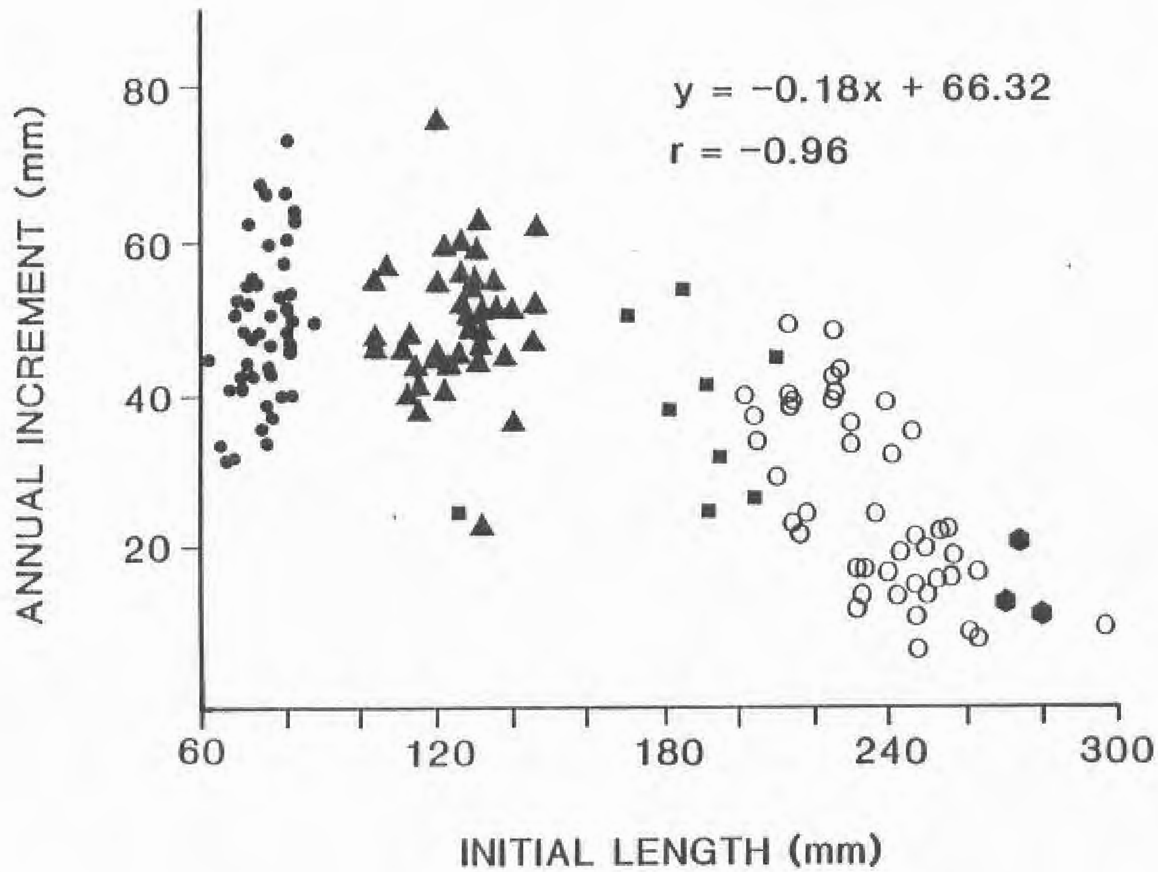

Figure 21. Initial length in last completed year of growth, versus annual growth increment for age-2 (●), -3 (▲), -4 (■), -5 (○), and -6 (⬢) yellow perch from East Lake Eureka, South Dakota.

were sampled. The correlation coefficient between initial lengths and growth increments (Appendix 10) was -0.61 ($P<0.01$) (Figure 22). The growth increments of the age-2 and -3 northern pike were especially variable. Growth rates for northern pike in lakes Oahe and Fort Randall in South Dakota were much higher (Carlander 1969); East Lake Eureka pike reached an average length of 535 mm TL by age-3 compared to 572 mm TL in Clear Lake, Iowa (Carlander 1969).

East Lake Eureka may have an excessive biomass of prey fish compared to predatory fish based on a comparison of the standing stock estimates (Table 2) of bluegill, yellow perch, and black bullhead with northern pike, the main predator in system. Further analysis of the biomass estimates of the prey versus predator fish was conducted by developing an available prey/predator (AP/P) ratio (Figure 23). The AP/P ratio was calculated based on the prey fish biomass that was available to the biomass of predators, based on mouth widths of predators and body depths of prey. A 1:1 ratio is a minimum desirable ratio of prey biomass to predator biomass in the late summer (Jenkins and Morais 1978). The Lake Eureka AP/P ratio was calculated for early summer, and the prey biomass would thus be expected to be in excess of the 1:1 ratio. This was true for the larger predators (> 51 cm); however, the biomass of smaller predators was larger than the prey biomass. Small fishes that would serve as prey for these smaller predators were

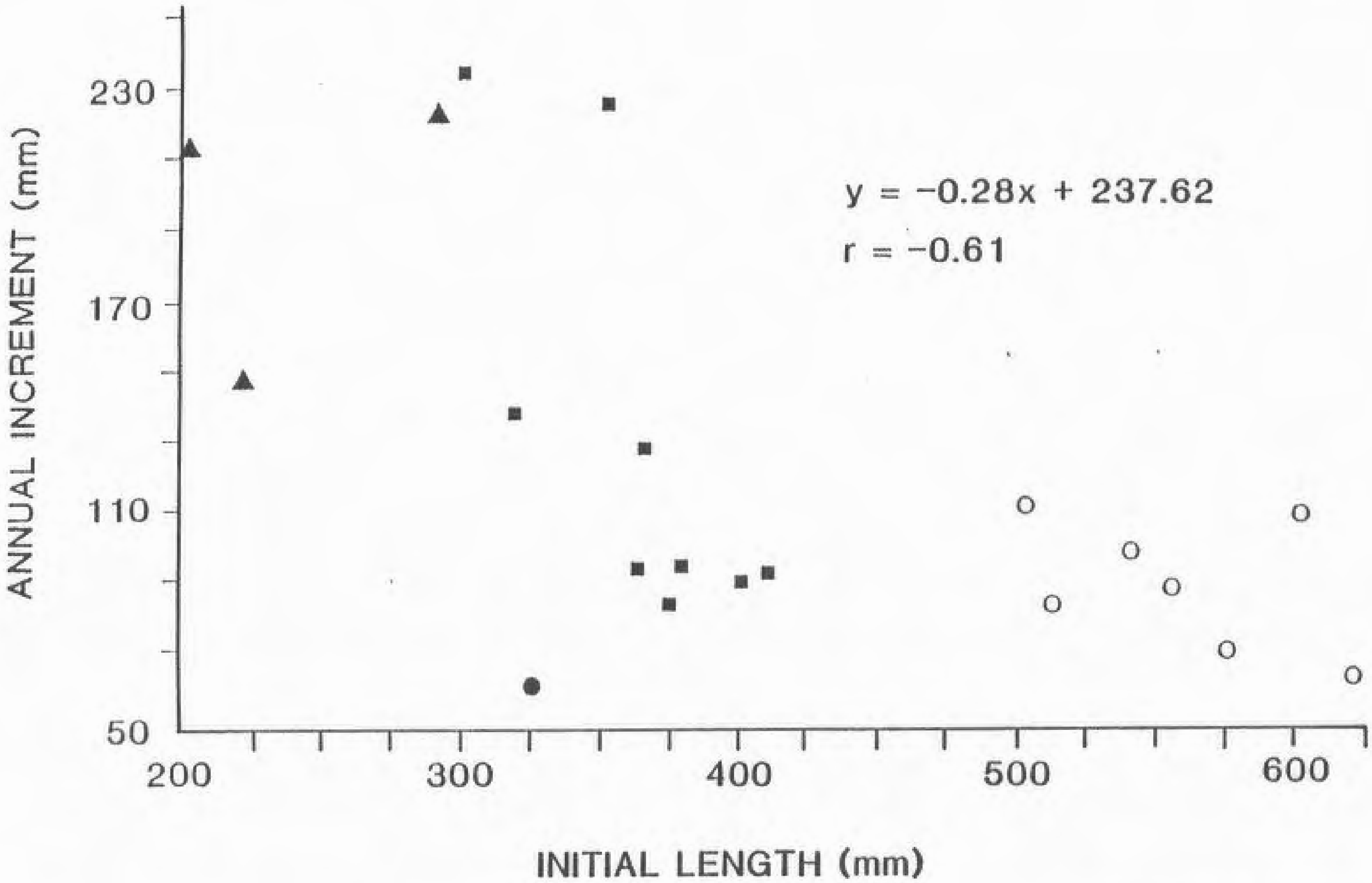

Figure 22. Initial length in last completed year of growth, versus annual growth increment for age-1 (●), -2 (▲), -3 (■), and -4 (O) northern pike from East Lake Eureka, South Dakota.

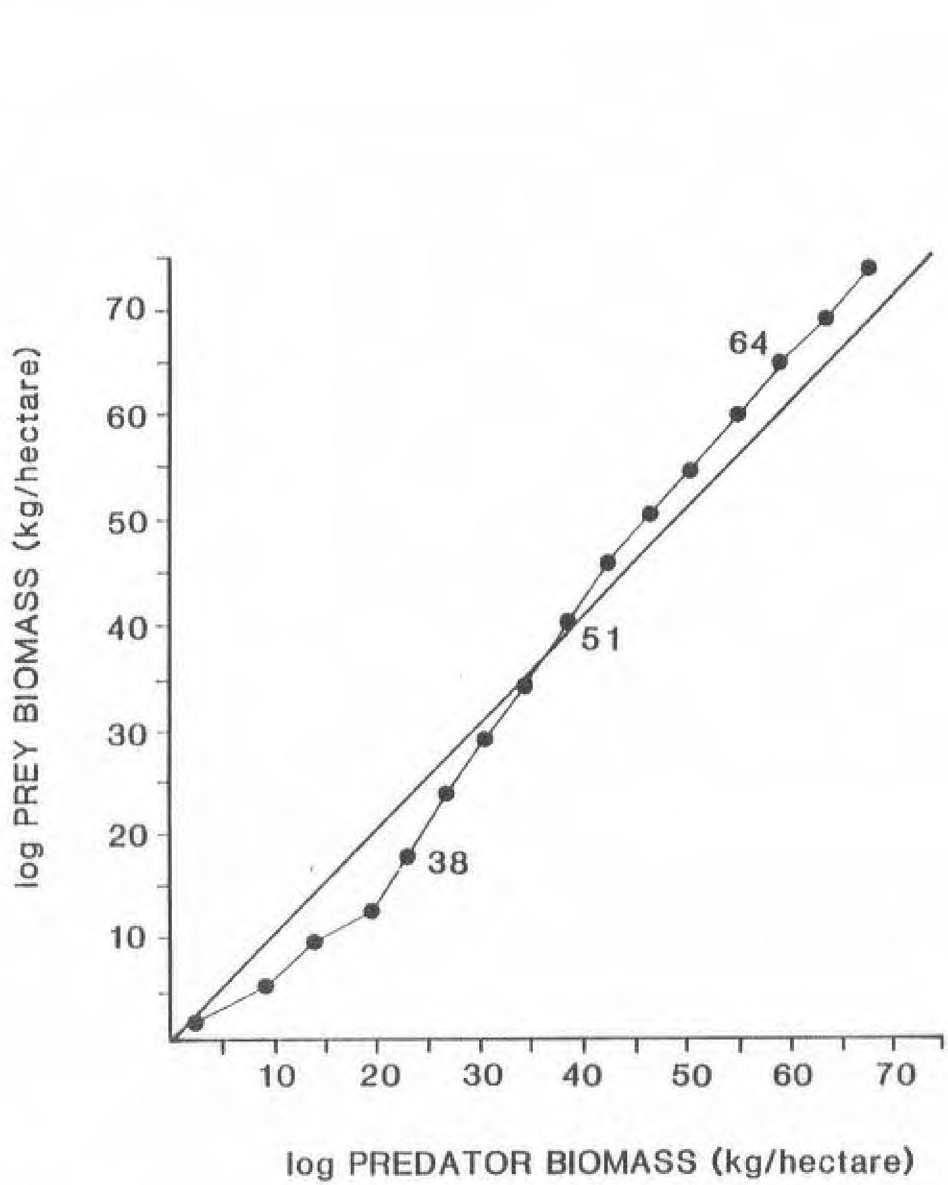

Figure 23. Available prey to predator ratio calculated for East Lake Eureka, South Dakota, in June 1986. Points refer to centimeter-size classes (by 2.5-cm increments) of northern pike and black bullheads with equivalent mouth widths. The 45° diagonal line is the 1:1 relationship between available prey and predators.

probably under-represented in samples due to the selectiveness of the techniques used. Young-of-the-year bluegills, yellow perch, and black bullheads likely would serve as prey for these smaller predators, but our sampling produced no estimates of the biomass of these fishes. Numerous banded killifish were observed in the shallows of East Lake Eureka and these fish would also be available prey for the smaller predators. An average of 94 banded killifish were captured per seine haul during August 1986, but no biomass estimates were made for these prey fish.

Management Implications

Triploid grass carp can be used effectively for aquatic weed control in South Dakota lakes and ponds. However, especially in the northern parts of the state, extremely high stocking rates may be necessary in order to achieve aquatic weed control. High stocking rates would be expensive because of the cost of the fish ($4-5/ 200-mm triploid grass carp) (Clugston and Shireman 1987); partial aquatic vegetation control might not be possible with high stocking rates. Wiley et al. (1987) recommended a 36-40% vegetation coverage of the littoral area as optimal for largemouth bass production, and made their stocking recommendations based on this target level. Lower stocking rates and serial stocking strategy (i.e., stocking additional grass carp as needed in subsequent years) may obtain partial vegetation reduction, but the results observed in this study did not indicate that this would be possible because no vegetation reduction was observed in Prior Lake until nearly total reduction was observed in 1987; this probably was a result of the high stocking rate. However, an even higher stocking rate on East Lake Eureka failed to affect aquatic vegetation through 1987. Perhaps partial or complete aquatic vegetation control may be observed on East Lake Eureka during the summer of 1988, and the use of triploid grass carp for vegetation control instead of eradication can be further evaluated then.

Fowler and Robson (1978) recommended stocking a sufficient number of grass carp to control the increase in less palatable plant species as the grass carp eliminate the more palatable species. Such higher stocking rates could again lead to aquatic vegetation eradication. Once grass carp reduce aquatic vegetation to desirable levels, part of the population could be removed, but grass carp are extremely long-lived (Hill 1986) and are difficult to capture using conventional gear. For example, only two of the grass carp stocked in this study were ever recaptured (one in a trap net and one by electrofishing). Grass carp were often observed in shallow water but they easily avoided capture. More research needs to be completed to see if, and how, triploid grass carp can be used for maintaining aquatic vegetation at optimum levels.

Higher than usual grass carp stocking rates may be necessary in extremely hard waters; this may be especially true when Chara is the predominant weed type. Hard water may have been one reason that aquatic weed reduction was not observed on East Lake Eureka after two years. The Chara may have been less palatable to the grass carp because of the calcareous coating on the plant.

The fish community composition also differed between Prior Lake and East Lake Eureka. Prior Lake contained largemouth bass, and grass carp were stocked at a mean length of 229 mm to avoid bass predation. However, northern pike were abundant in East Lake Eureka, and 229 mm grass carp would be vulnerable to predation by the pike. Grass carp show little predator-avoidance behavior (Shireman et al. 1978, Stanley et al. 1978). Thus, grass carp predation by northern pike might also be responsible for the lack of vegetation control in East Lake Eureka.

This study was too short to detect any changes in existing fish populations due to grass carp introduction and subsequent aquatic vegetation removal. Also, unexpected factors were present that complicated any observations concerning the existing fish populations; one was the winterkill that occurred in Prior Lake in early 1986. In addition, sport-fishing harvest could have had an effect on fish populations in both East Lake Eureka and Prior Lake, especially because both lakes were located in or adjacent to their respective municipalities.

Aquatic vegetation removal may expose a prey fish, like bluegills, to predation from largemouth bass (Heman et al. 1969). However, if predatory fish species become more vulnerable to angling at the same time, the results could be undesirable. Although no measurements of angler harvest were made during this study, such a scenario could be possible on Prior Lake. Clearly, the data collected in this study, although they may have been limited, indicated an over-abundance of small bluegills in Prior Lake. Harvest of more largemouth bass with the elimination of aquatic vegetation would only make the situation worse. Establishment of more restrictive regulations (e.g. length limits) for largemouth bass could help correct the situation, but would be difficult to enforce due to the nature of the angling public there; i.e. the children from town.

The available prey/predator ratio (Figure 23) for East Lake Eureka suggested that an over-abundance of prey fish could be a possibility there as well. Prey for yellow perch in East Lake Eureka was abundant in the form of the banded killifish, yet the poor condition and slow growth rates of the yellow perch indicated stunting and over-population. The large biomass of yellow perch and black bullheads in

East Lake Eureka suggests that the system may need additional predators. Walleyes and largemouth bass are present in East Lake Eureka, but in low numbers. Supplemental stockings of largemouth bass and/or walleyes might improve the predator base in East Lake Eureka. Such fish, if stocked, would probably have to be at least advanced fingerlings or larger in order to survive due to the fish already present; thus, such stockings would be expensive. Transplanting of juvenile or adult largemouth bass from another body of water would have the greatest chance for success, but also would be quite expensive.

Finally, it must be restated that the effect of grass carp introduction and aquatic vegetation removal on the fish populations in both Prior Lake and East Lake Eureka remain to be evaluated. Not enough time has elapsed or changes have not been great enough to cause any noticeable effects thus far. Given more time, any of the conclusions drawn in this study may prove invalid as conditions progress and change in both East Lake Eureka and Prior Lake. Additional study of these systems after more time has passed should clarify the effectiveness of triploid grass carp in controlling aquatic vegetation, whether this control can be maintained at some optimal vegetation level, and how grass carp introduction and aquatic vegetation reduction will affect existing fish populations.

Management Recommendations

1. Triploid grass carp can be used for aquatic vegetation control in small lakes and ponds in South Dakota.
2. A stocking density of 49 grass carp/hectare (20 fish/acre) that are approximately 250 mm in length should be sufficient to reduce excessive aquatic vegetation within two years in waters containing largemouth bass.
3. Further research is needed to determine whether larger sizes of grass carp must be stocked in waters containing northern pike.
4. Additional research is needed to determine the possibility of partial aquatic vegetation reduction by grass carp.
5. Further research is needed to determine whether stocking rates should be based on the total area of a lake, the area of aquatic vegetation coverage, or some other measure of the extent of aquatic vegetation.
6. Efforts should be made (through regulation changes, stockings, or other management practices) to keep fish populations in balance as aquatic vegetation is reduced.

7. In East Lake Eureka, additional grass carp should be stocked or other methods should be used to control the aquatic vegetation problem.
8. Aquatic vegetation levels in East Lake Eureka and Prior Lake should continue to be monitored following the methods established in this study. Measurements should be made at least once during the summer during peak aquatic vegetation levels (mid-July).
9. Fish populations in Prior Lake should be sampled in 1989 in order to determine what changes in fish populations have occurred following aquatic vegetation removal. Such data could be compared to the "pre-treatment" data gathered in this study.
10. When, and if, aquatic vegetation reduction is observed in East Lake Eureka, fish populations there should be sampled to determine what changes have occurred.

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APPENDICES

Appendix 1. Percent aquatic vegetation coverage along the respective transects in Prior Lake, South Dakota, throughout the study period.

Date		Transect #					
		1	2	3	4	5	mean
1985	22 May	99	77	97	33	0	61
	22 July	92	76	89	0	0	51
1986	21 May	100	64	74	0	0	48
	09 June	100	59	78	0	0	47
	30 June	89	57	73	0	0	44
	21 July	97	66	73	0	0	47
	11 Aug	91	65	77	0	0	47
1987	12 May	66	48	55	0	0	34
	28 May	60	48	48	0	0	31
	22 June	7	23	3	0	0	7
	14 July	4	0	8	0	0	2
	03 Aug	0	3	8	0	0	2
	24 Aug	2	4	5	0	0	2

Appendix 2. Percent of water column occupied by aquatic vegetation along the respective transects in Prior Lake, South Dakota, throughout the study period.

Date	Transect #					
	1	2	3	4	5	mean
1985 22 May	87	59	86	10	0	48
22 July	48	46	61	0	0	31
1986 21 May	48	40	45	0	0	27
09 June	63	50	66	0	0	36
30 June	68	53	65	0	0	37
21 July	57	41	39	0	0	27
11 Aug	37	30	34	0	0	20
1987 12 May	8	13	7	0	0	6
28 May	7	9	8	0	0	5
22 June	6	3	4	0	0	3
14 July	0	0	0	0	0	0
03 Aug	0	6	2	0	0	2
24 Aug	0	0	3	0	0	1

Appendix 3. Percent aquatic vegetation coverage along the respective transects in East Lake Eureka, South Dakota, throughout the study period.

		Transect #					
Date	1	2	3	4	5	6	mean
1985 04 June	30	49	38	82	65	60	54
23 July	64	78	52	100	76	74	74
1986 22 May	0	58	73	82	0	41	42
12 June	94	83	84	94	72	70	83
01 July	18	77	96	88	53	63	66
17 July	35	81	93	92	65	62	71
12 Aug	12	76	98	95	45	68	66
1987 13 May	34	73	85	98	40	65	66
04 June	20	74	92	97	32	67	64
23 June	32	77	100	94	37	60	67
22 July	14	79	100	94	41	62	65
04 Aug	15	79	100	94	37	60	64
20 Aug	24	72	100	88	45	61	65

Appendix 4. Percent of water column occupied by aquatic vegetation along the respective transects in East Lake Eureka, South Dakota, throughout the study period.

Date		Transect #						
		1	2	3	4	5	6	mean
1985	04 June	4	2	6	17	15	9	9
	23 July	11	55	41	41	24	39	35
1986	22 May	0	28	26	43	0	19	19
	12 June	21	74	52	61	21	52	47
	01 July	0	62	70	67	23	66	48
	17 July	2	69	74	74	17	61	50
	12 Aug	5	70	77	72	9	67	50
1987	13 May	6	50	59	63	14	42	39
	04 June	5	78	77	70	44	43	53
	23 June	8	60	78	77	28	52	50
	22 July	7	63	80	71	39	65	54
	04 Aug	8	76	74	74	26	48	51
	20 Aug	7	73	80	79	15	51	51

Appendix 5. Percent aquatic vegetation coverage along the respective transects in West Lake Eureka, South Dakota, throughout the study period.

Date	Transect #				
	1	2	3	4	mean
1985 04 June	90	100	82	100	93
23 July	100	100	100	100	100
1986 22 May	0	0	0	0	0
13 June	83	74	22	14	48
01 July	91	100	100	96	96
17 July	91	100	97	92	95
12 Aug	91	96	100	96	96
1987 13 May	78	74	46	59	64
04 June	74	72	82	93	80
23 June	90	83	100	100	93
22 July	100	81	100	97	94
04 Aug	90	73	99	95	89
20 Aug	97	82	97	95	93

Appendix 6. Percent of water column occupied by aquatic vegetation along the respective transects in West Lake Eureka, South Dakota, throughout the study period.

Date	Transect # 1	2	3	4	mean
1985 04 June	17	19	8	36	20
23 July	60	69	61	73	66
1986 22 May	0	0	0	0	0
13 June	36	19	2	0	14
01 July	58	65	11	32	42
17 July	59	65	35	60	55
12 Aug	65	58	45	49	54
1987 13 May	34	28	4	26	23
04 June	53	31	34	44	40
23 June	67	49	51	56	56
22 July	76	73	63	58	68
04 Aug	75	61	84	56	69
20 Aug	72	68	66	69	69

Appendix 7. Age, initial length, and annual growth increment of largemouth bass from Prior Lake, South Dakota, in 1987.

Age	Initial length (mm)	Annual growth increment (mm)
2	76	85
2	91	96
2	108	77
2	93	60
2	74	107
2	97	65
2	134	55
2	93	121
2	80	59
2	118	47
2	52	40
3	175	46
3	143	56
3	206	46
3	208	46
3	173	38
3	188	50
3	185	30
3	177	51
3	144	54

Appendix 8. Age, initial length, and annual growth increment of bluegill from East Lake Eureka, South Dakota, in 1986.

Age	Initial length (mm)	Annual growth increment (mm)
2	44	50
2	46	61
2	53	65
2	44	54
2	44	54
2	42	42
2	36	43
2	44	46
2	50	58
2	52	63
2	49	66
2	50	57
2	58	64
2	53	67
2	54	67
2	54	71
2	40	43
2	49	55
2	47	42
2	37	43
2	43	41
2	50	48
2	45	55
2	40	22
2	44	65
2	44	41
2	44	51
2	48	73
2	41	42
2	48	56
2	48	49
2	33	42
2	40	50
2	48	62
2	46	71
2	42	45
2	35	44
2	49	70
2	46	53
2	48	62
2	50	59
2	42	42

Appendix 8 (continued).

Age	Initial length (mm)	Annual growth increment (mm)
2	52	49
2	55	49
2	51	58
2	52	41
2	49	60
2	47	51
2	49	49
2	54	70
2	54	76
2	55	69
2	51	67
2	51	63
2	51	67
2	52	70
2	29	49
2	52	68
2	29	49
2	52	68
2	32	35
2	33	31
2	36	33
2	53	71
2	39	38
2	35	39
3	112	61
3	122	33
3	95	35
3	82	56
3	99	38
3	135	25
3	103	41
3	118	51
3	116	58
3	117	61
3	112	52
3	107	41
3	132	26
3	101	76
3	118	61
3	111	63
3	86	65
3	83	72
3	100	61
3	132	47

Appendix 8 (continued).

Age	Initial length (mm)	Annual growth increment (mm)
3	100	71
3	129	33
3	139	28
3	98	64
3	122	52
3	126	31
3	102	40
4	179	19
4	204	14

Appendix 9. Age, initial length, and annual growth increment of yellow perch from East Lake Eureka, South Dakota, in 1986.

Age	Initial length (mm)	Annual growth increment (mm)
2	70	53
2	79	47
2	70	51
2	83	49
2	69	32
2	59	45
2	80	40
2	79	37
2	81	58
2	70	41
2	79	43
2	91	50
2	79	51
2	71	49
2	72	55
2	80	53
2	84	46
2	84	54
2	72	48
2	83	50
2	84	41
2	73	45
2	76	55
2	84	47
2	78	44
2	81	52
2	78	39
2	77	49
2	85	47
2	84	40
2	84	47
2	74	56
2	86	40
2	82	51
2	82	52
2	77	68
2	82	74
2	76	48
2	72	43
2	78	67
2	84	55
2	77	36

Appendix 9 (continued).

Age	Initial length (mm)	Annual growth increment (mm)
2	72	48
2	68	46
2	81	66
2	83	63
2	83	64
2	70	43
2	75	43
2	78	34
2	74	63
2	74	56
2	79	60
2	82	67
2	68	41
2	67	32
2	63	34
3	121	47
3	120	45
3	122	46
3	126	45
3	137	51
3	139	55
3	125	60
3	136	44
3	130	45
3	132	48
3	134	59
3	134	44
3	140	45
3	135	46
3	139	51
3	118	44
3	141	36
3	126	44
3	123	59
3	118	41
3	123	41
3	131	54
3	124	44
3	129	56
3	114	55
3	146	48
3	121	55
3	119	38
3	148	47

Appendix 9 (continued).

Age	Initial length (mm)	Annual growth increment (mm)
3	132	50
3	115	40
3	130	47
3	134	55
3	121	76
3	141	51
3	110	57
3	114	46
3	136	48
3	128	60
3	128	52
3	114	46
3	149	52
3	114	48
3	135	23
3	115	48
4	188	54
4	193	25
4	127	25
4	197	32
4	213	45
4	194	41
4	174	50
4	206	26
4	183	38
5	215	40
5	249	15
5	255	22
5	264	8
5	248	7
5	263	17
5	254	16
5	228	40
5	220	24
5	219	22
5	258	16
5	248	35
5	218	39
5	261	9
5	249	21
5	235	14
5	243	19
5	231	36
5	241	32

Appendix 9 (continued).

Age	Initial length (mm)	Annual growth increment (mm)
5	259	19
5	227	39
5	213	29
5	216	38
5	297	10
5	231	33
5	243	14
5	229	43
5	242	17
5	204	40
5	238	17
5	240	39
5	253	14
5	242	19
5	234	12
5	235	17
5	249	11
5	217	23
5	207	34
5	251	20
5	258	22
5	227	42
5	217	49
5	227	48
5	239	24
5	206	37
6	277	21
6	274	13
6	280	11

Appendix 10. Age, initial length, and annual growth increment of northern pike from East Lake Eureka, South Dakota, in 1986.

Age	Initial length (mm)	Annual growth increment (mm)
1	325	61
2	293	223
2	207	213
2	223	148
3	302	236
3	357	227
3	414	92
3	379	94
3	322	138
3	401	90
3	375	83
3	363	93
3	368	128
4	503	112
4	605	109
4	518	84
4	576	70
4	624	63
4	545	98
4	558	88