POSSIBLE CAUSES OF THE SMALL AVERAGE SIZE OF CRAPPIE IN SOME OKLAHOMA RESERVOIRS

By

WILLIAM FRANCIS SCHOCH

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Cornell University
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Thesis Approved

Michael D. Clady
Thesis Adviser

O. Eugene Maughan

Ronald W. McNew

Norman N. Durham
Dean of the Graduate College

PREFACE

This research was funded by the Oklahoma Department of Wildlife Conservation. It is the initial phase in a program to develop management techniques to reduce the problem of stunting in black and white crappie (*Pomoxis nigromaculatus* and *P. annularis*). The literature was reviewed and the relation between diet and growth rates of crappie was evaluated.

Gene Stout, Director of Fort Sill Military Reservation's Department of Fish and Wildlife, provided equipment, labor and housing for the work done on Fort Sill. This aid was an indispensable supplement to the funds received for the project and is greatly appreciated.

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

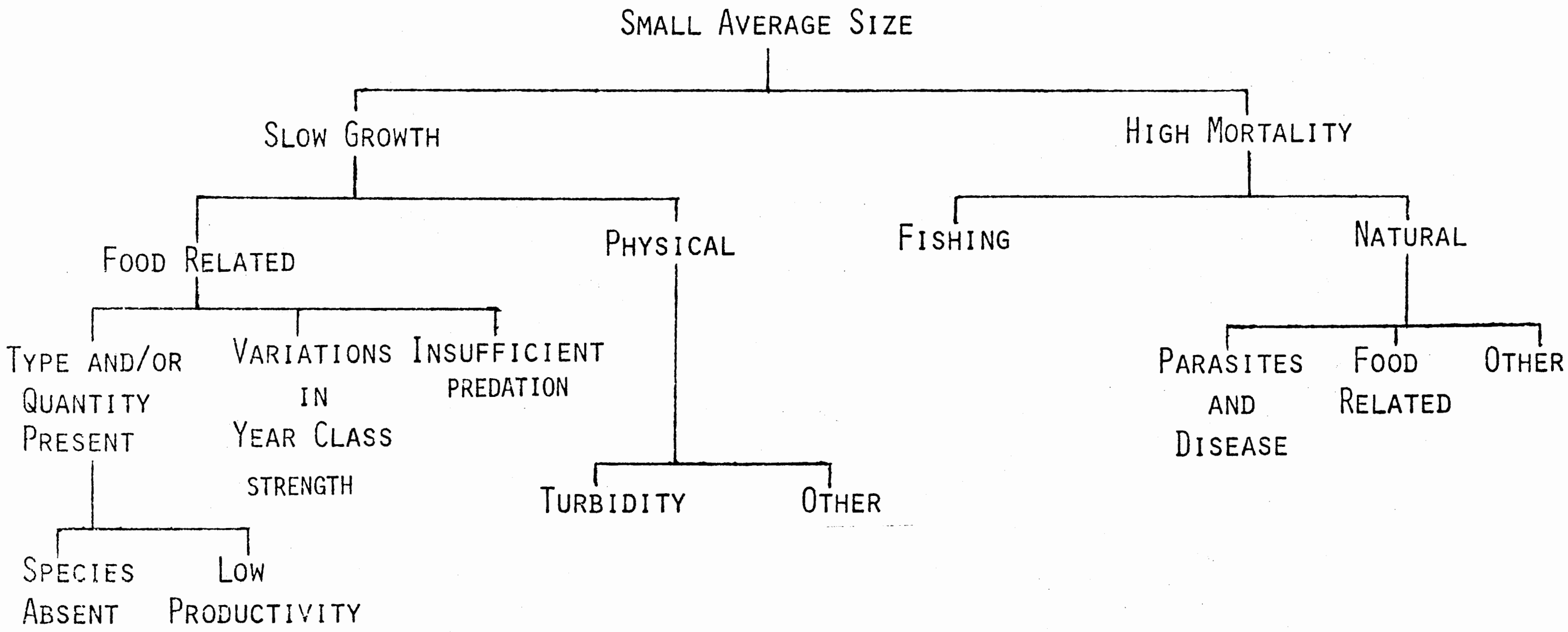
INTRODUCTION

Populations of black and white crappie (_Pomoxis_ _nigromaculatus_ and _P_. _annularis_) in many of Oklahoma's lakes (small reservoirs) and larger reservoirs are comprised mostly of individuals that are too small to be desired by fishermen. Considering that a recent survey of Oklahoma anglers found that crappie were the third most preferred, and the second most frequently sought after fish (Mense 1978), the small average size of crappies in many bodies of water is an important management problem in the state.

The relatively low proportion of large fish in many populations appears to be the result of both high mortality of older fish and of slow growth. However, in some populations growth appears rapid and mortality low. For example, age IV white crappies in Boomer Lake averaged 208 mm (total length), and only 9.7% of the population was age IV and older (Crawley 1954; Burris 1956). In Lake Texoma more rapid growth (to an average of 257 mm for age IV fish) and higher survival of older fish (24.0% of the population was age IV or older) combined to produce a much higher percentage of crappies large enough to be creeled (Whiteside 1974).

Numerous biological and physical factors may result in small average size (Figure 1) but one major factor is high mortality. Although the causes of high mortality of age III and older crappies in

Figure 1. Flow chart of factors affecting the average size of crappies.


SMALL AVERAGE SIZE
SLOW GROWTH
HIGH MORTALITY
FOOD RELATED
PHYSICAL
FISHING
NATURAL
TYPE AND/OR QUANTITY PRESENT
VARIATIONS IN YEAR CLASS STRENGTH
INSUFFICIENT PREDATION
TURBIDITY
OTHER
PARASITES AND DISEASE
FOOD RELATED
OTHER
SPECIES ABSENT
LOW PRODUCTIVITY

Oklahoma have not been determined, the traditional explanation is that the crappies are overabundant, and that competition and stresses associated with overcrowded conditions result in high mortality rates. This hypothesis is supported by several studies. High natural mortality of age III crappie was observed by Starrett and Fritz (1965) who found 60 to 75% mortality during the fourth year of life. Of that mortality, 5% was due to fishing and 95% was natural. The authors did not indicate what may have caused the natural mortality. Further support for this hypothesis is indicated in certain lakes in Kansas where few crappies age IV and older were found, even though fishing pressure was low (Stafford 1979). Based on the traditional explanation that intense competition causes slow growth and high mortality of older fish, it follows that increased fishing pressure will alleviate the situation by reducing the level of competition (Rutledge and Barron 1972).

Not all the data agrees with this high natural mortality hypothesis. For example, recent work in Missouri indicated that harvest itself may be a major source of mortality (Vasey 1979). Fishing pressure on crappies in the James River Arm of Tablerock Reservoir was much greater than in the Long Creek Arm. Growth rates were similar and rapid for both arms, but very few older crappies were present where fishing pressure was relatively high. The abundance of crappies that were age IV and older in the Long Creek Arm indicated that fish in the James River Arm had the potential to live longer than they actually did. A creel survey showed that, in the James River Arm, fishermen were harvesting the largest crappies available. The mortality due to fishing was not measured, but probably accounted for the scarcity of older, larger crappies where harvest was high (Vasey 1979). Preliminary results indicate that reduction of harvest through a size and possession limit has increased survival of crappies that are age IV and older.

Although Vasey observed fast growth and high mortality of older crappies, the typical explanation is that stunting occurs in the younger age classes. Therefore, it initially appears unlikely that increased exploitation of crappies would reduce densities and improve growth of younger year classes. Crappie are extremely prolific (Jenkins 1957), and even a major reduction in the spawning stock of older, larger individuals appears unlikely to reduce long-term recruitment.

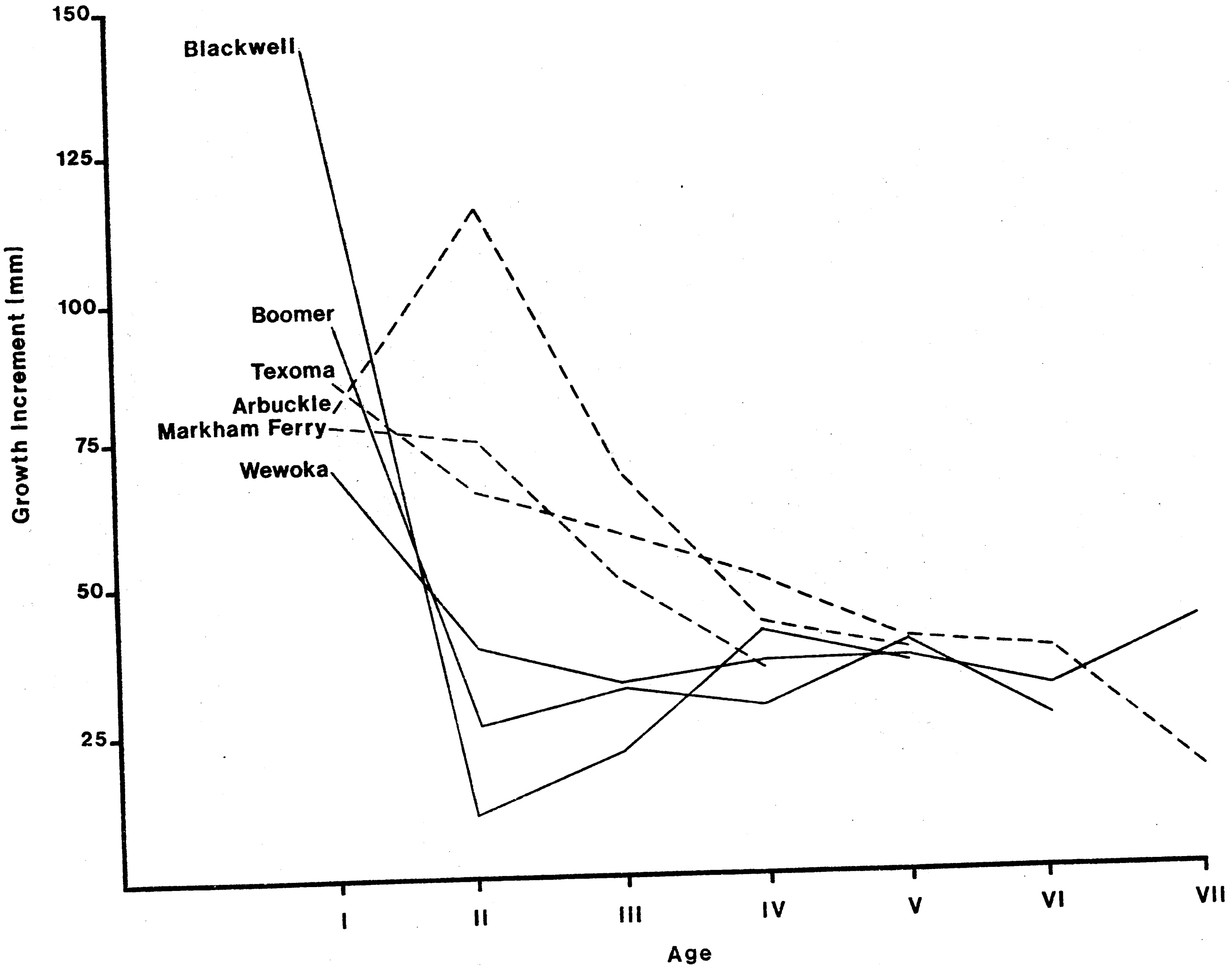
In addition, food habit changes also appear to limit the effectiveness of increased harvest as a management tool. Fish tend to become important in the diet of crappies at about 150 mm in length (Reid 1949; Burris 1956; Green and Murphy 1974), whereas crappies less than 150 mm eat mostly invertebrates and zooplankton. Thus, the diet generally changes from invertebrates to fish when the crappies are less than, or first approaching the size at which removal by fishermen occurs. Thus, anglers remove only the larger crappies and do not reduce the degree of food competition among the smaller crappies.

If harvest is reducing competition among larger crappies but not among smaller crappies, then growth should change only in older groups. Studies by Crawley (1954) and Burris (1956) of slow growing crappie populations indicated that growth was slow up to about 150 mm in length, and then became more rapid. Similar patterns were suggested by data collected by the Oklahoma Department of Wildlife Conservation from other lakes (unpublished data). For example, harvestable crappies were relatively rare in lakes Carl Blackwell, Boomer, and Wewoka but relatively common in lakes Texoma, Arbuckle and Markham Ferry. Growth increments were similar for yearlings and older, larger crappies from both types of populations (Figure 2), but differed considerably for young, sub-harvestable crappies. A reduction of competition among sub-harvestable crappies through harvest of larger fish may have accounted for the differences in growth rates.

Direct interactions between harvestable and sub-harvestable segments of the population through predation may also effect rate of growth. Adult crappies in Beaver Reservoir in Arkansas were cannibalistic and preferred young-of-the-year crappies over any of the other forage fish available (Ball and Kilambi 1972). Cannibalism by adults could be a density dependent control on the abundance of young. If this hypothesis is true, harvest could increase competition among smaller crappies and decrease growth rates. Conversely, large numbers of adults would limit survival of, and competition among young, and therefore growth of young would be enhanced. Heavy angler harvest would also reduce cannibalism, increase competition and possibly decrease growth.

It is my conclusion that the literature does not support the common belief that slow-growing crappie populations should be intensely harvested. The shift in diet which occurs before crappies reach a harvestable size prevents fishermen from reducing competition during the life stage where it appears to be a problem. Depending on the degree of cannibalism and the intensity of harvest, removal of larger crappie could actually increase competition among young by increasing survival.

Figure 2. Annual growth increments of white crappie from lakes where growth is relatively good (--) and relatively poor (—).


150
125
100
75
50
25
Growth Increment (mm)
Blackwell
Boomer
Texoma
Arbuckle
Markham Ferry
Wewoka
I
II
III
IV
V
VI
VII
Age

In areas where high mortality does not result from fishing, parasites and diseases are a possible natural cause. However, the literature does not indicate that these factors have widespread importance or are severe enough to cause the 60 to 75% natural mortality that has been observed (Rutledge and Barron 1972). For example, in Lake Texoma, only up to 8% of the crappies had lymphocystis (Whiteside 1964), and approximately 9% of the crappies in Benbrook Lake, Texas were infected (Green and Murphy 1974). In Benbrook Lake average condition factors of infected fish were slightly lower than for uninfected crappies, but neither study indicated that disease was a likely source of mortality.

Slow growth of crappies has also been related to a variety of other conditions. Hall et al. (1954) found that in Oklahoma growth was generally better in clear water than in turbid water. In a Missouri reservoir, growth increased greatly when Secci disk readings (transparency) increased from an average of about 0.3 m to 1.0 m (Vasey 1979). Crappies are primarily sight feeders, so high turbidities could reduce feeding efficiency. However, crappies also are known to grow slowly in some relatively clear waters (Leonard 1951; Martin 1952; Crawley 1954).

Crappies frequently grow relatively fast in new reservoirs and reservoirs on fertile watersheds (Hall et al. 1954). Such bodies of water generally have high productivity and might be expected to support either a greater biomass of fish, or faster growing fish if food were limiting.

Growth rates also appear to be related to the size of a reservoir (Hall et al. 1954). On the average, crappies in large reservoirs grow more slowly than those in smaller bodies of water; however, many of the small reservoirs (lakes) studied had only recently been impounded. The faster growth in these small lakes was probably as much related to their age as their size. Crappies generally do not grow rapidly in older small lakes (Hall et al. 1954).

Competition for space where crappies are very abundant could possibly limit growth (Bennett 1970). However, crappie are a schooling fish so competition for some factor other than space appears more likely. Insufficient cover is also a possible cause of slow growth, although the literature reviewed gave no indication of whether an absence of such cover could affect the well-being of crappies (Miller and Robison 1973).

Slow growth of crappies is most generally proposed to result from insufficient food. One condition that could produce an overabundance of fish relative to the food supply is insufficient predation on small crappies. Pierce et al. (1963), Swingle and Swingle (1967), and Tucker (1972), working with largemouth bass (Micropterus salmoides), and Powell (1973), working with northern pike (Esox lucius), found that abundance of predators was directly related to growth of crappies. Apparently predation continuously thinned the population, reducing competition and increasing growth.

A strong year class could also lead to intense competition and slow growth (Thompson 1941). Apparent cycles of three to five years have been reported in year class strength (Starret and McNeil 1952; Swingle and Swingle 1967; Siefert 1969). Cycles could result from increased competition and slow growth following one or two strong year classes. In these cases cannibalism might limit the abundance of subsequent year classes until mortality reduced the abundance of the dominant year classes. A period would follow in which crappies were scarce but grew relatively fast. Reduced cannibalism would then allow production of another strong year class.

The size and quantity of forage may also determine whether or not crappies grow well. The diets of individual crappie pass through three generalized stages. Very small crappies, particularly young-of-the-year, feed primarily on zooplankton. Crappies up to about 150 mm total length eat mostly benthic invertebrates whereas larger crappies eat mostly fish (Burris 1956). Recently, populations of threadfin shad and Mississippi silversides (Menidia audens) have been established in various Oklahoma lakes and reservoirs as forage for crappie. Crappies will feed heavily on these species, and their introductions have, in some instances, been associated with increased growth of crappies (Beers and McConnell 1966; Li et al. 1976). In these instances the availability of forage fish may have been limiting growth. However, both studies noted that the introduced species may also compete with young crappies since Li et al. (1976) found that even though over-all growth of crappies increased, growth during the first two years of life actually decreased. In addition, in lakes where threadfin shad had a short spawning season, small shad were available for a limited time and crappies grew poorly (McConnell and Geddes 1964; Menn 1965; Beers and McConnell 1966). Competition with forage species could also result in increased mortality of young and associated improved growth of older fish. Insufficient data were taken before the introduction of these forage species to allow us to determine the effect on crappies.

Burris (1956) compared food habits of slow and fast growing crappie populations and found fish were common in the diet of crappies under 150 mm where growth was good, and absent where growth was slow. This finding suggested that the quality of forage fish available to small crappies could determine rates of growth. Crawley (1954) and Siefert (1969), however, suggested that forage fish were not required for fast growth of crappies under 150 mm, but that larger insects, including Ephemeroptera, Diptera and Coleoptra, could substitute for fish in the diet of faster growing crappie. These authors concluded that the diet of slow growing populations consisted primarily of smaller invertebrates (Siefert 1969).

The general concensus of this study seem to indicate that food habits appear to be related to growth rates of crappies. However, the data are conflicting. Crawley (1954) and Burris (1956) both indicated that the diet of fish under 150 mm long was important, but Burris concluded that fish were necessary for good growth, while Crawley suggested the size of invertebrates consumed was more significant. Li et al. (1976) found the introduction of threadfin shad was associated with an overall increase in growth of crappies even though growth during the first two years decreased. It is possible that competition between young crappies and forage fish such as threadfin shad reduces survival of the crappies and results in increased growth by reducing competition.

Various attempts have been made to increase growth rates of crappie (Rutledge and Barron 1972). The relative success of these attempts offer insight as to the causes of slow growth, and of high mortality of fish older than age III. Netting and poisioning have been used to remove a portion of the crappie populations from lakes where growth was slow; under the assumption that high densities produce intense competition and slow growth. Generally, when 30% or more of the population was removed growth of the remaining fish increased. However, without continued thinning, the populations rapidly expanded and reverted to the high-density, slow-growing state. The results of thinning and predator-stocking experiments, as discussed above, indicate that growth rates in some lakes are density dependent, which suggests that either the forage base, space, or cover were limiting growth of crappies.

The relation between level fluctuations and growth of crappies has been studied in Kansas (Beam 1979). Water levels were lowered throughout the summer, allowing terresterial vegetation to grow on exposed portions of the reservoir bottom. In spring the reservoirs were allowed to refill, flooding the vegetation. Growth was unaffected although it was expected that annual flooding of this nature would produce conditions similar to those in a newly filled reservoir and, therefore, promote good growth (Beam 1979).

The small average size of crappies in many of Oklahoma's ponds and reservoirs is a complex problem. Physical factors such as turbidity appear to limit growth in some bodies of water. Also, studies of food habits, forage introductions, and reductions in density suggest that competition for food also limits growth. In addition, the relative contribution of natural and fishing mortality to low abundance of fish age IV and older is unknown. Any one of these factors may be important in a given reservoir, and the interaction of two or more may be significant in many bodies of water. However, it is necessary to know which of these factors are limiting, and how they may interact, before crappie populations can be managed effectively.

The objective of this study was to evaluate the relation between various aspects of the forage supply and growth. I compared growth rates and condition factors for populations of relatively fast growing crappie to those of relatively slow growing crappie. I also determined the important items in stomachs of crappies and estimated relative abundance of these primary forage organisms.

CHAPTER II

METHODS

Experimental Design

Four fish populations, including fast and slow growing white and black crappie, were studied. We tested the following null hypotheses:

H_o: Forage was equally abundant in lakes (small reservoirs) where growth of crappies was fast and slow.

H_o: The average amount of food in stomachs of crappies was the same in lakes where growth was fast and slow.

Rejection of either of these hypotheses would suggest that forage abundance was related to growth of crappies.

Discrepencies between abundance, as measured by the sampling equipment, and the actual availability of food items to crappies could have confounded the results. The consequences of such discrepancies were minimized by the following:

1. The same procedures were used in each lake to estimate abundance of forage. If the availability of a given organism was misrepresented by those procedures, then the bias should be the same for all lakes, and the results comparable on a relative basis.
2. Abundance was estimated only for organisms important in the diet. This assured that bias of the sampling gear for

organisms not eaten did not influence the relative importance of items actually in their diet.

Bias due to gear selectivity was probably minimal if the types of organisms consumed were similar in all lakes and abundance changed in direct proportion to changes in diets. The sampling gear was likely to underestimate or overestimate the abundance of some organisms. If those organisms made up similar proportions of the diets for fish from different lakes then the effect of the bias was similar between lakes. If those organisms made up different proportions of the diet between lakes then the effect of the bias was different between lakes.

The quantity of stomach contents may not have been a relative measure of caloric content of food eaten, since caloric content can vary from one type of forage to another. Therefore, the types of forage consumed by each population were also compared.

Description of Study Area

Four lakes were selected for study based on the following criteria:

1. Crappie populations with different growth rates. The four lakes included relatively fast and slow growing fish of both species.
2. Relatively old lakes. Fast growing crappies have previously been studied in new lakes (Crawley 1954; Burris 1956). Since crappies usually grow well for the first three to five years in a new reservoir, after which growth rates may decrease (Thompson et al. 1951), Burris and Crawley may have observed temporary conditions, and possibly conditions eventually

leading to poor growth. The lakes with fast growing crappies selected for this study were over ten years old and probably provided stable conditions supporting good growth.

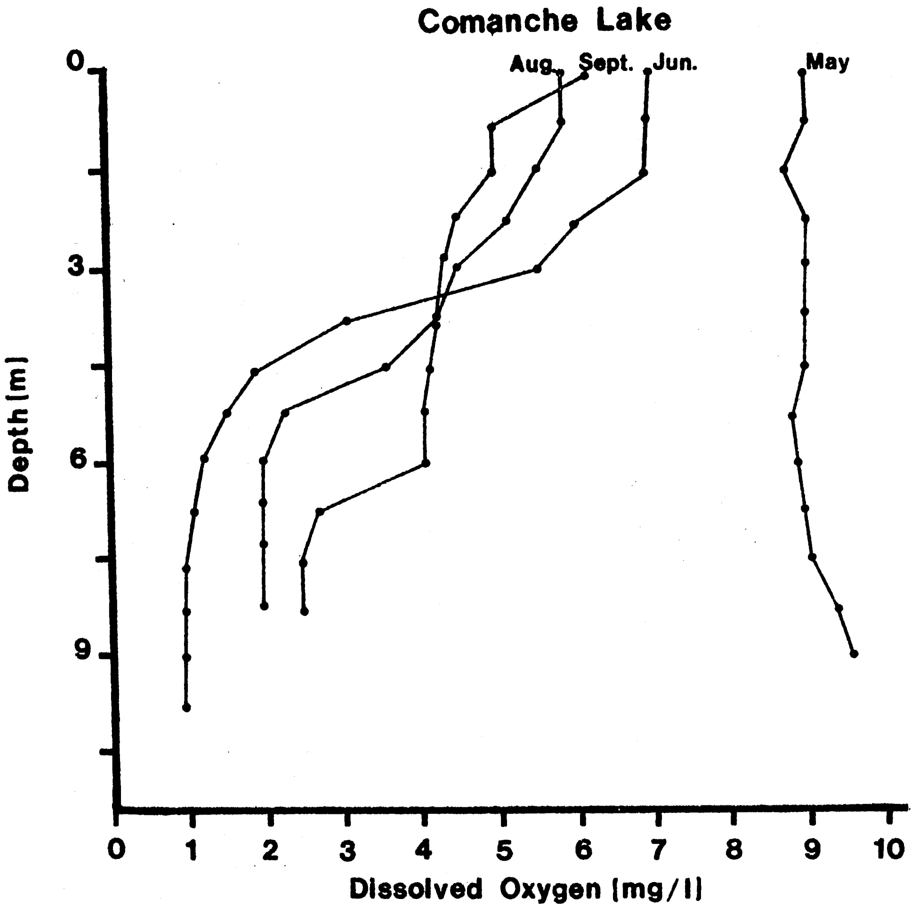
3. Small size of the lakes. Lakes under 40 ha were selected so that sampling problems were minimized and results were applicable to state owned reservoirs (under 65 ha) where the management potential is greatest.
4. Low turbidity. Since growth of crappies may be reduced by high turbidity (Hall et al. 1954), I selected lakes with relatively low turbidity (for Oklahoma waters).
5. Convenient location. It was necessary that lakes be located where labor, equipment, and inexpensive lodging were available.

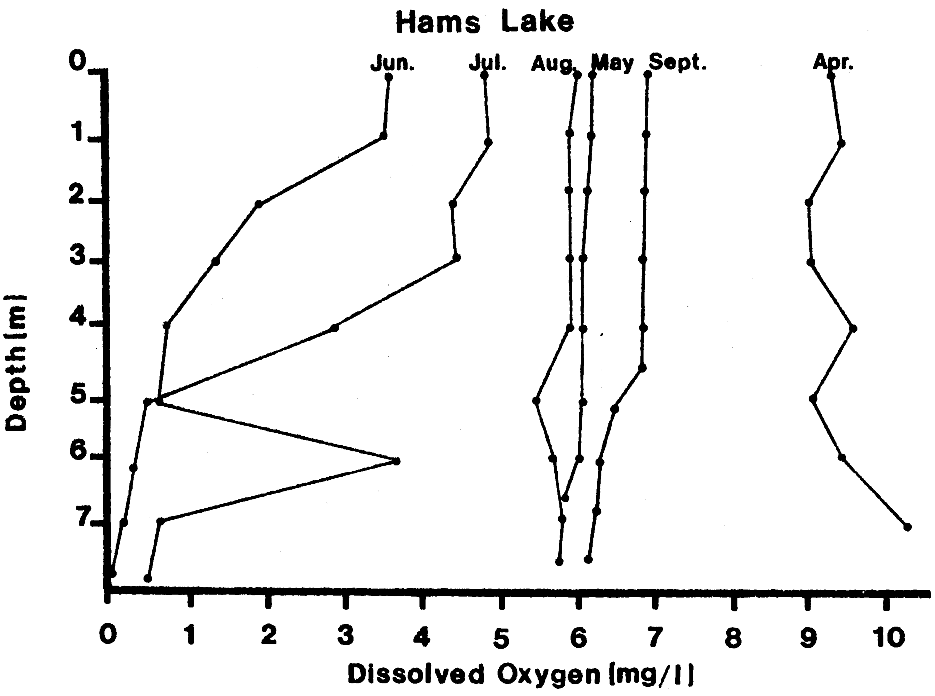
Two of the study lakes contained white crappie and two contained black crappie. The lakes with black crappie were:

1. Ham's Lake, west of Stillwater, Oklahoma (Section 22, Township 19N, Range 1E). Ham's Lake has a surface area of 40 ha, a capacity of 115 hectare meters, and a spillway elevation of 287 msl (Steichen 1974). Ham's Lake is relatively deep, with a maximum depth of 9.4 m. The lake tends to stratify in the summer and dissolved oxygen is reduced in the deeper waters (Figure 3). A mechanical mixing device is operated on Ham's Lake (Steichen 1974). The mixer shortens the period of stratification, as indicated by the August dissolved oxygen profile.

   Ham's Lake was relatively clear during the first year of the study, but became very turbid during the second year. Secchi disk transparency averaged 1.05 m from July 1979 to

Figure 3. Dissolved oxygen profiles of Comanche and Hams lakes during various months.


Comanche Lake
Aug.
Sept.
Jun.
May
Depth (m)
0
3
6
9
0
1
2
3
4
5
6
7
8
9
10
Dissolved Oxygen (mg/l)


Hams Lake
Jun.
Jul.
Aug.
May
Sept.
Apr.
Depth (m)
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
8
9
10
Dissolved Oxygen (mg/l)

April 1980. Then, apparently due to intense and prolonged rains, transparency decreased to an average of 0.30 m in May 1980 and averaged 0.32 m from then to September 1980. Extensive beds of macrophytes grew to a depth of roughly 1.5 m during the first year; however, after the dramatic decrease in transparency, macrophytes were rare during the summer of 1980.

Vernon very fine sandy loam and Vernon loam soils make up almost all of the watershed. These are shallow to very shallow soils (13-38 cm deep) underlaid by clay. Infiltration of water is slow, and erosion is a problem when the land is cultivated. Therefore, most of the area is range land and native vegetation (Cobb and Hawker 1918).

2. Comanche Lake on the Wichita Mountains Wildlife Refuge (Section 1, Township 3N, Range 15W). Comanche Lake has a surface area of 21 ha, a conservation storage capacity of 111 hectare meters, and a spillway elevation of 554.7 msl (Oklahoma Water Resources Board 1976).

Comanche Lake has a maximum depth of 9.9 m, about the same as Ham's Lake. However, because of its steeper profile, Comanche has an average depth of about 5 m compared to 3 m for Ham's Lake. Comanche Lake stratifies during the summer and dissolved oxygen is low in the deeper waters (Figure 3).

Comanche Lake was clear throughout the study. The average Secchi disk reading was 2.2 m and it ranged from 1.25 to 3.0 m. Dense beds of macrophytes extended from the shoreline to areas as deep as 5.5 m. Myriophyllum sp. was the dominant macrophyte; Ceratophyllum sp. was common and some Potamogeton sp. were present.

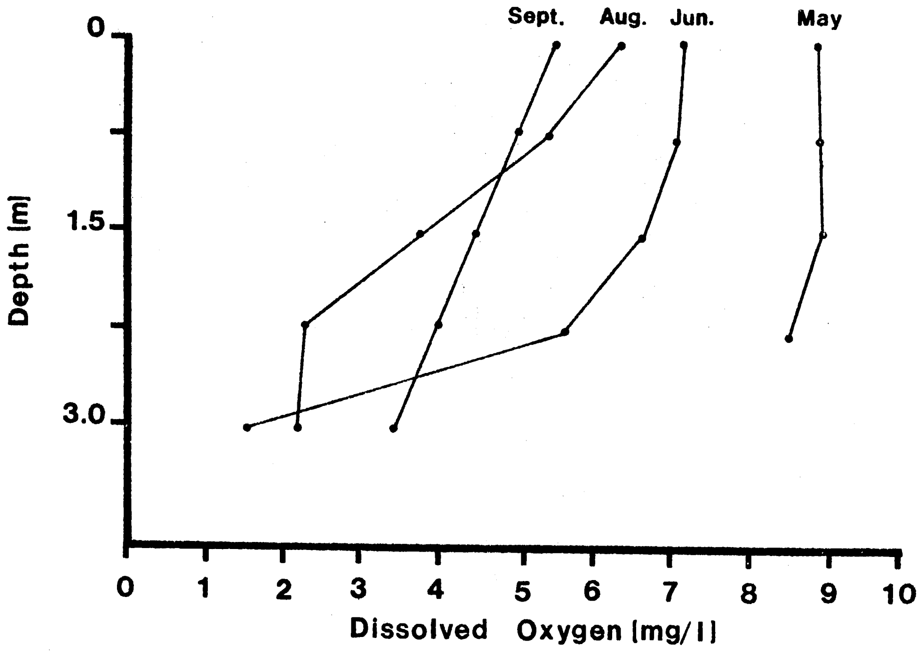
The entire watershed of Comanche Lake consists of rock land and stoney rock land. These are very shallow soils over granite bedrock, with gentle to moderately steep slopes. Range land is the only appropriate use for these areas, and they are managed as such for wildlife as part of the Refuge (U.S. Department of Agriculture 1967).

The lakes with white crappie were:

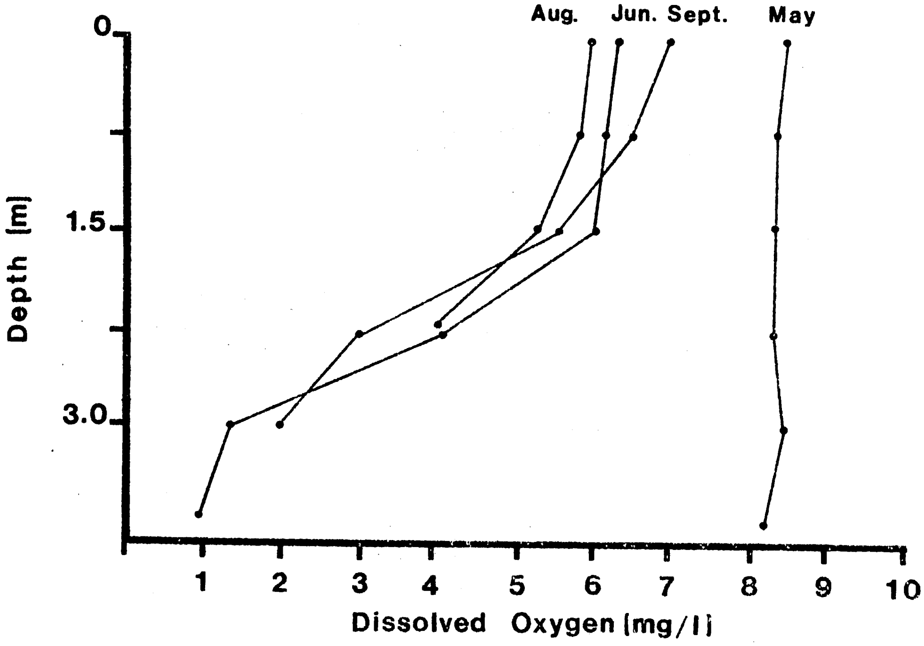
1. Lake George on Fort Sill Military Reservation (Section 15, Township 2N, Range 11W). Lake George has been reported to have a surface area of 119 ha, a conservation storage capacity of 555 hectare meters, and a spillway elevation of 347 msl (Oklahoma Water Resources Board 1976). However, on the basis of plainimeter readings from air photographs, I estimated the surface areas to be about 37 ha. That figure seems more realistic based on casual observations of the lake's size during the study. The maximum depth in Lake George is about 6 m. The lake stratified to some degree; however, the zone of oxygen depletion was not as pronounced as in Comanche or Ham's lakes (Figure 4).

   Lake George remained relatively clear throughout the study. Secchi disk transparencies averaged 1.03 m and ranged from 0.75 to 1.5 m. Substantial beds of macrophytes grew to a depth of about 2 m. During 1979, when water levels were near the drainpipe level, the macrophytes produced a broad, dense border around the lake, but the majority of the lake

Figure 4. Dissolved oxygen profiles of lakes George and Logan during various months.



Lake George



Logan Lake

remained open. In 1980 the water level ranged from about 1 to 2 m below the drain pipe. The reduced depth allowed macrophytes to grow over a much larger area, and approximately half of the lake area consisted of dense growths of macrophytes. _Myriophyllum_ sp. was the only macrophyte observed.

Soils have not been surveyed near Lake George or on Fort Sill in general. This watershed, like the watersheds of the other lakes involved in the study, consists largely of native vegetation. None of the land is cultivated.

2. Logan Lake on the Fort Sill Military Reservation (Section 16, Township 2N, Range 13W). The surface area and storage capacity of Logan Lake are unknown; however, I estimated the size to be 11 ha based on planimeter readings from air photographs. The surface elevation is 390 msl.

The maximum depth of Logan Lake is about 5 m. The lake stratified during summer; however, like Lake George, the zone of oxygen depletion was not as pronounced as in Ham's and Comanche lakes (Figure 4). Logan Lake remained relatively turbid throughout the study. Secchi disk readings averaged 0.31 m and ranged from 0.20 to 0.50 m. Only a few sparse patches of _Myriophyllum_ sp. were present.

Soil types are unknown, and natural vegetation covers the watershed. There are frequent fires near both lakes George and Logan, which maintain grassland on these watersheds.

Data Collection and Analysis

Crappie

Adult crappies were collected primarily with hoop nets similar to those described by Houser (1960). Seines, a 3700 watt AC electrofishing boat (4.9 m), 45.7 m experimental gill nets (19 to 63.5 mm bar mesh), trap nets, and hook and line were also used. Lengths to the nearest mm and weights to the nearest g were measured on all fish in smaller catches. When catches were larger, all of the fish in some nets were weighed and measured by length, whereas the catch in other nets was only counted by species.

Scales (collected from the side near the tip of the pectoral fin) and stomachs were removed from individuals representing the full size distribution of fish collected. When fish were being collected for stomach analysis the nets were generally emptied every morning and evening, and frequently more often.

Growth rates were determined from cellulose acetate impressions of the scales (Tesch 1971) and aged independently by two people. Growth rates were back-calculated by computer and the relation between total scale radius and total length was determined. (In all instances a linear relation was found.) Correction factors and slopes were then computed and used in a second program that back-calculated lengths. Growth increments during each year of the study were then determined and tested for significant differences, with analysis of variance.

Fish used for stomach analysis were usually collected in the morning because food in their stomachs was less-digested than food in stomachs of fish caught in the evenings (unpublished data). Immediately after the fish were taken from the nets, stomachs were surgically removed from the larger crappies and wrapped in cheese cloth. Smaller fish were preserved whole and stomachs later removed in the lab. Fish and stomachs were preserved in 10% formalin.

Food was analyzed in the following manner:

1. The contents were removed from the stomachs and blotted dry.
2. The total volume of the contents was measured by water displacement in a graduated centrifuge tube.
3. Organisms were generally identified to family or order (Pennak 1953; Usinger 1956) under a dissecting microscope and the number of items in each taxon was determined.
4. The volume of each taxon was measured by displacement. When the volume of a taxon from a stomach was too small to be measured, it was based on the number of individuals and an average volume per individual estimated from stomachs where quantities for the taxon were larger, and from forage collected by dredge and plankton net.
5. Percent occurrence of each taxon was based on the number of stomachs that contained food.

Average volume of stomach contents per crappie and per gram of crappie were calculated for each month and year. The sign test (Conover 1971) was used to test for a consistent relation between monthly averages of growth and volume of food.

Forage Abundance

Zooplankton was collected from May to October 1979 and from May to September 1980. Four horizontal tows each month were made with a

0.115 m diameter Wisconsin-type plankton net having 80 μ mesh. When possible two surface and two deep (∿1.5 m) tows were made; however, in some instances macrophytes and shallow water limited collection to surface tows. If the combination of surface and deep tows had to be modified on one lake, then it was also modified on the other lake containing the same species of crappie so that the sampling bias would be similar. Generally two tows were made adjacent to the dam and two in the upper end of each lake.

The average distance of a tow was 170 m, taken at a speed of about 57 m/min. A flow meter mounted on the side of the boat determined the volume strained by each tow. Samples were preserved in 10% formalin. Zooplankton was identified (Pennak 1953) and enumerated using 1 ml subsamples in a Sedgewick-Rafter counting chamber. Three subsamples per tow were counted and densities were estimated as follows:

$$\text{No./m}^3 = \frac{[(\text{Average No./ml of sample}) \text{ X } (\text{Volume of sample (ml)})]}{[(\text{Area of net opening } (\text{m}^2) \text{ X } (\text{Length of tow (m)})]}$$

Benthic invertebrates were collected with an Ekman dredge (225 cm^2) monthly from May to October 1979 and from May to September 1980. On each date, eight sites were chosen at random in areas of each lake where it was possible to sample. Samples were washed through a #30 mesh sieve at the lake, and preserved in 10% formalin. Invertebrates were separated, identified (Pennak 1953; Usinger 1956), and counted in the lab. The volume of each taxon was measured and the volume of invertebrates important in the diet of crappies was calculated per unit area.

CHAPTER III

RESULTS

Conditions in a lake can change greatly from year to year, as can growth rates of fish. Therefore, it was important to confine the measure of growth to the period when environmental factors were also measured. Fish collected in 1980 were used to determine growth increments during all of 1979. However, fish could not be collected in 1981 to determine growth during all of 1980. Instead fish collected during August and September 1980 were used. Thus the 1979 and 1980 growth increments were calculated for different lengths of time, and should not be compared to each other.

Growth increments were greater (by 18-52%) for white crappies age I and older from Lake George than Logan Lake for both years (Table 1). The differences were non-significant in 1979 (0.098), but significant in 1980 ($p = 0.000$). In 1979 yearling crappie in Logan Lake grew slightly faster than those in Lake George, however, the opposite was true for all of the older year classes. Overall growth was therefore significantly greater in Lake George than Logan Lake. Gear selectivity limited the number of yearlings collected for stomach analysis. Stomachs were collected primarily from the older crappie which grew significantly faster in Lake George than in Logan Lake and consequently it is appropriate to refer to the stomach data from Lake George as representing faster growing fish than that from Logan Lake.

Table 1. Growth increments of white crappies of various ages from lakes George and Logan during 1979 and 1980.

Year of life	Lake and growth (mm)			
	January-December 1979		January-September 1980	
	George[1]	Logan[1]	George[2]	Logan[2]
0-1	76	83	-	74
1-2	49	39	67	29
2-3	35	23	18	12
3-4	-	24	13	11
4-5	33	25	-	9
5-6	-	38	-	-

[1] Statistically different at the 0.098 level.

[2] Statistically different at the 0.0001 level.

Growth increments were greater (by 6-36%) for black crappies of given ages from Comanche Lake than Ham's Lake in 1979 (p = 0.046), but were statistically similar (greatest difference = 18%) in both lakes in 1980 (p = 0.424 level; Table 2). Thus, contrasting growth could be related to other factors for both years with white crappie, but for only 1979 with black crappie. (Detailed data on age and length frequencies are presented in Appendix A. Condition factors are presented in Appendix B.)

Relative volumes of stomach contents were not closely correlated with growth. The sign test showed no relations between the monthly average volume of stomach contents per individual and growth (significant at the 0.48 level; Table 3). Monthly average volume per gram of fish was negatively related to growth. The relation was significant at the 0.10, but not at the 0.05 level (Table 4).

Annual average volumes of stomach contents indicate the same patterns. In two instances (white crappies in 1980 and black crappies in 1979), the annual average volume of stomach contents per gram of fish (Table 5) was greater (by 48-69%) where growth was slow than where growth was fast. When growth rates of white crappies also differed in 1979, however, populations contained nearly identical mean volumes of food per biomass. Also, in 1980 black crappies grew at similar rates in both lakes, yet the mean volume of food eaten per biomass was 39% greater in Comanche Lake. Although the pattern was not consistent, the average volume of stomach contents per gram of fish tended to be greater where growth was slow than where growth was fast.

Annual average volumes of stomach contents per fish also were not closely related to growth (Table 6). Volumes per black crappie were

Table 2. Growth increments of black crappies of various ages from Comanche and Hams lakes during 1979 and 1980.

Year of life	January-December 1979		January-September 1980	
	Comanche[1]	Hams[1]	Comanche[2]	Hams[2]
0-1	117	99	-	74
1-2	61	50	-	45
2-3	37	35	45	38
3-4	32	23	24	24
4-5	-	-	15	14
5-6	9	-	-	-

[1] Statistically different at the 0.046 level.

[2] Statistically different at the 0.424 level.

Table 3. Relative growth rate and monthly average volume of stomach contents (X 10^3) per individual black and white crappie from various lakes, 1979 and 1980. [The symbol in parentheses indicates if the amount of food was greater in the lake with faster (+) or slower (-) growth.[1]]

Year	Species	Lake	Growth rate	Month and mean volume (ml)/individual X 10^3					
				May	June	July	Aug.	Sept.	Oct.
1979	White crappies	George	Fast	18.2	267.0	74.2	-	95.2	421.1
		Logan	Slow	89.0	426.8	135.3	-	100.0	11.5
				(-)	(-)	(-)	-	(-)	(+)
	Black crappies	Comanche	Fast	63.0	145.0	121.9	-	261.5	0.0
		Hams	Slow	-	-	58.8	58.3	55.6	160.0
				-	-	(+)	-	(+)	(-)
1980	White crappies	George	Fast	76.2	28.8	350.0	146.8	94.1	-
		Logan	Slow	171.4	163.6	254.5	0.0	312.5	-
				(-)	(-)	(+)	(+)	(-)	
	Black crappies	Comanche	Similar	966.7	140.0	198.1	261.5	306.3	-
		Hams	Similar	88.9	97.9	200.0	347.4	375.0	-

[1] Sign test: 13 trials, 5 were (+); statistically different at the 0.48 level (two-tailed test).

Table 4. Relative growth rate and monthly average volume of stomach contents per gram ($X\ 10^3$) of black and white crappies from various lakes, 1979 and 1980. [The symbol in parentheses indicates if the amount of food was greater in the lake with faster (+) or slower (-) growth.[1]]

Year	Species	Lake	Growth rate	Month and mean volume (ml)/g $X\ 10^3$					
				May	June	July	Aug.	Sept.	Oct.
1979	White crappie	George	Fast	0.47	4.96	2.22	-	2.83	5.64
		Logan	Slow	2.27	6.23	3.88	-	3.31	0.51
				(-)	(-)	(-)	-	(-)	(+)
	Black crappie	Comanche	Fast	0.42	1.25	0.77	-	2.04	0.00
		Hams	Slow	-	-	1.43	1.11	1.04	1.74
				-	-	(-)	-	(+)	(-)
1980	White crappie	George	Fast	1.08	0.70	5.31	3.90	2.24	-
		Logan	Slow	2.57	4.05	6.98	0.00	8.73	-
				(-)	(-)	(-)	(+)	(-)	
	Black crappie	Comanche	Similar	9.55	0.84	1.26	1.87	2.73	-
		Hams	Similar	1.43	1.51	2.96	5.34	0.43	-

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[1] Sign test: 13 trials, 3 were (+); statistically different at the 0.092 level (two-tailed test).

Table 5. Yearly average volume of stomach contents per gram (X 10^3) of black and white crappies from various lakes, 1979 and 1980.

Species and lake	Mean volume (ml)/g X 10^3 1979	 1980
White crappie		
George	3.22	2.65
Logan	3.24	4.47
Black crappie		
Comanche	0.90	3.25
Hams	1.33	2.33

Table 6. Yearly average volume of stomach contents (X 10^3) per individual black and white crappie from various lakes, 1979 and 1980.

Species and lake	Mean volume (ml)/individual 1979	 1980
White crappie		
George	175.1	139.2
Logan	152.5	180.4
Black crappie		
Comanche	118.3	374.5
Hams	83.2	263.1

42% greater in Comanche Lake in 1980, yet growth rates in Ham's Lake were similar to those in Comanche Lake. The second greatest difference was between the white crappie populations in 1980, when slow growing individuals in Logan Lake had eaten 29% more than the fast growing individuals in Lake George. In 1979, the pattern was reversed for both black and white crappies; i.e., 23-42% more food per fish was eaten where growth was fast (lakes George and Comanche) than where growth was slow. Food habits do not support the hypothesis that fast growing fish ate more than slow growing fish. Overall the results were inconsistent, and the results of approximately one-half of the comparisons were the opposite of what would be expected.

Caloric content, rather than volume of stomach contents may be related to growth rates. I assumed that average volume of stomach contents was an approximation of caloric intake. However, caloric content per gram of wet weight varies greatly between different types of forage (Table 7). If slow and fast growing fish consumed different types of forage, then the caloric content per unit volume of stomach contents may have been different. According to previous workers (Crawley 1954; Burris 1956) differences in types of forage consumed may be more significant than total quantity in determining growth.

The results of this study, however, did not indicate that the type of forage consumed was closely related to growth. The relative importance of fish, benthic invertebrates, and zooplankton in the diet (Table 8) was highly variable for both fast and slow growing fish. For crappies from 100 to 149 mm total length, fish and benthic invertebrates were more important in 1979 in the diet of fast growing crappies than slow growing crappies. Zooplankton constituted most of

Table 7. Caloric content of various organisms found in stomachs of black and white crappies.

Taxon	Calories Gram wet weight	Calories Gram dry weight
Cladocera	-	5241
Daphnia	314	5028
Copepoda		
Diaptomidae	550	5741
Cyclopidae	-	5788
Amphipoda	934	4002
Insecta	759	4823
Ephemeroptera	-	5469
Odonata	-	5117
Diptera	613	4276
Chironomidae	656	5424
Centrarchidae	-	4677
Clupeidae	1927	6360

[1] From Cummins and Wuycheck (1971).

Table 8. Relative importance of fish, benthic invertebrates, and zooplankton in the diets of black and white crappies from four lakes, 1979 and 1980. (Unidentified remains bring totals up to 100 percent.)

Size class of crappie (mm)	Year	Taxon	Species, lake and percent (by volume) of stomach contents			
			White crappie		Black crappie	
			George	Logan	Comanche	Hams
100-149	1979	Fish	5	<0.1	49	0
		Benthic invertebrates	73	41	43	7
		Zooplankton	18	59	0	63
	1980	Fish	<0.1	73	87	8
		Benthic invertebrates	95	25	12	75
		Zooplankton	5	1	1	4
150-over	1979	Fish	77	87	11	35
		Benthic invertebrates	13	11	57	50
		Zooplankton	10	2	22	5
	1980	Fish	79	83	9	76
		Benthic invertebrates	18	15	82	12
		Zooplankton	0.4	<0.1	4	0.4

the diet where growth was fast. In 1980, however, the patterns were very different. Fish were more important, and zooplankton was scarce in the diet of slow growing white crappies relative to fast growing white crappies. Benthic invertebrates remained abundant where growth was fast relative to where growth was slow. On the other hand, the importance of benthic invertebrates differed greatly in the diets of the two black crappie populations where growth rates were similar.

The relative importance of each type of forage was also highly variable for crappie greater than 150 mm total length (Table 8). Where growth was fast the percentage of fish, benthic invertebrates, and zooplankton in the diet varied from 11 to 79, 13 to 57, and 0.4 to 22, respectively. Where growth was slow fish made up from 35 to 87% of the diet, benthic invertebrates from 11 to 50% and zooplankton from less than 0.1 to 5%. Fish tended to be rare, and benthic invertebrates and zooplankton were more common in stomachs where growth was fast relative to where growth was slow. However, the differences were probably not significant. Also, in the instance where growth rates were similar (black crappies in 1980), the diets of the two populations were very different.

The next question was whether actual abundance of forage in the environment, rather than growth (a possible function of forage abundance), was related to diet. This relation was difficult to investigate, however, because different units were used to measure the abundance of different organisms. To minimize the problems we ordinally compared abundance of a given organism in two lakes or years with the importance of that forage in the diets of the corresponding sample of crappies. For example, if benthic invertebrates were more abundant during 1980 than during 1979 in Lake George, then it would be expected that they made up more of the diet during 1980 than 1979.

However, the abundance of benthic invertebrates and zooplankton in the diet of fish within a lake did not appear to be correlated to the organism's relative abundance in the environment in different years. Although benthic invertebrates are generally considered to be the main component in the diet of crappies 100 to 149 mm in length, abundance in the environment changed in the same direction as the change in importance in the diet only in Lake George (Table 9). In two lakes (Logan and Hams) the changes were in opposite directions, and in Comanche Lake abundance in the environment remained constant but importance in the diet declined. For 16 similar comparisons made between years within lakes for both benthic invertebrates and zooplankton and for both size groups of crappies (Table 10), higher environmental abundance was associated with greater importance in the diet only eight times. Thus, although benthic invertebrates and zooplankton tended to be more abundant where growth was fast than where growth was slow, these differences in abundance did not appear to be directly related to differences in diets.

Table 9. Abundance of benthic invertebrates in the environment relative to importance in the diet of black and white crappies 100-149 mm total length, 1979 and 1980.

	Species and lake							
	White crappie				Black crappie			
	George		Logan		Comanche		Hams	
Year	Environment (no./m^2)	Diet (% total volume)	Environment (no./m^2)	Diet (% total volume)	Environment (no./m^2)	Diet (% total volume)	Environment (no./m^2)	Diet (% total volume)
1979	0.028	73	0.024	41	0.101	43	0.056	7
1980	0.054	95	0.031	25	0.101	12	0.032	75
Change	+0.026	+22	+0.007	-16	0.0	-31	-0.024	+68

Table 10. Abundance of forage types in the environment relative to importance in the diet of crappies of two sizes.

Crappie size group (mm)	Forage type	Comparison of changes between years within lakes		Comparison of changes between lakes within years	
		Expected[1]	Not expected	Expected[1]	Not expected
100-149	Benthic invertebrates	1	3	3	1
	Zooplankton	2	2	2	2
>149	Benthic invertebrates	3	1	4	0
	Zooplankton	2	2	3	1
	Totals	8	8	12	4

[1] Expected means greater abundance in the environment was associated with greater importance in the diet.

CHAPTER IV

DISCUSSION

The data showed that growth was either not related to food intake (based on average volume of stomach contents per fish) or negatively correlated with food intake (based on average volume of stomach contents per gram of fish). Of the two measures, the average volume of stomach contents per fish may be a more appropriate measure because the ultimate concern of this study was production of crappies of harvestable size. Paloheimo and Dickie (1965, p. 527) stated "...the same absolute ration appears to lead to the same absolute growth rate no matter what the size of fish."

The relation between food consumption and the resulting growth is very complicated. The equation $pR = T + {}^{\Delta w}/_{\Delta t}$, where R is the ration consumed, p is a factor to adjust for incomplete digestion of the food consumed, T is the total energy metabolized, and ${}^{\Delta w}/_{\Delta t}$ is growth, has been presented by Paloheimo and Dickie (1965, 1966a, 1966b) as a useful guide for organizing discussion of this relationship. Although applying this equation quantitively is complex and beyond the scope of this study, the equation basically states that energy that is consumed and not excreted is either metabolized or used for growth. Given the following assumptions:

1. Average volume of stomach contents provided a relative measure of the energy consumed (average volume was directly propor-

tional to R).

2. Of the energy consumed the proportions excreted were the same for the crappie populations being compared (p for white crappies in Lake George = p for white crappies in Logan Lake, and p for black crappies in Comanche Lake = p for black crappies in Hams Lake).
3. Total metabolism was similar for the populations being compared (T for white crappies in Lake George = T for white crappies in Logan, and T for black crappies in Comanche = T for black crappies in Hams).

Then it follows that a greater average volume of stomach contents would result in greater growth. Since this result did not occur, one or more of the above assumptions were apparently invalid.

Several factors, including caloric content and seasonal and daily variations in feeding patterns, affect the validity of assuming that average volume of stomach contents was a relative measure of energy intake. For example, variations in daily feeding patterns could have biased the observed volume of stomach contents. As a result of a short period of intense feeding each day, volume of stomach contents is large shortly after feeding and small just before the next period of feeding. Conversely, extended periods of feeding each day result in more consistent volumes of food in the stomach (Eggers 1977). If crappies tended to feed intensively for short periods, and if this feeding period occurred at different times in the various lakes, then the volume of stomach contents would be highly variable, and the bias produced in each lake would have differed depending on the times of feeding. However, the argument for different feeding periods for fish from different lakes is not supported by the numerous studies that have indicated that crappies tended to feed continuously (Burris 1956; Seaburg and Moyle 1964; Keast 1968; Tucker 1972). The assumption of food volume being equal to energy consumed is supported by the work of Crawley (1954). This author varied his sampling throughout the day in order to eliminate any bias due to a short period of feeding and found a greater average volume of stomach contents where growth was slow than where growth was fast. Altogether, the literature suggests that daily feeding patterns should not have had a great influence on the relative measure of energy intake.

Different digestive rates could also limit the usefulness of volume of stomach contents as a relative measure of energy intake. Given the same food intake, fish that are rapidly digesting food will at any given time have a smaller volume of stomach contents than fish that digest food more slowly. The digestive rate of fish is temperature dependent (Tolg 1962; Kitchell and Windell 1968). In this study relative high temperatures (up to $27.2^{o}C$) could have caused the measure of food (energy) consumed to be underestimated; however, metabolism would also have been higher and proportionally less energy would have been available for growth. To some degree the two effects would cancel each other, producing an unknown, but smaller net effect. Regardless, differences in temperature did not appear to explain the results. In 1980, when slow growing white crappies in Logan Lake apparently consumed more than fast growing white crappies in Lake George, temperatures were similar (often the same, and never differed by more than $1.6^{o}C$) in areas of the two lakes where levels of oxygen were suitable (Table 11).

Table 11. Minimum and maximum water temperatures (^{o}C) in areas of lakes George and Logan that had dissolved oxygen concentrations of 3.0 ppm or more.

	Date and lake							
	May 1980		June 1980		August 1980		September 1980	
	George	Logan	George	Logan	George	Logan	George	Logan
Maximum	20.0	20.0	26.1	26.7	26.6	27.2	25.0	25.6
Minimum	20.0	19.4	24.4	25.0	25.6	26.7	23.9	24.4

Seasonal variations in feeding may also have influenced the usefulness of volume of stomach contents as a relative measure of total energy intake. In 1979 stomachs were collected for a six-month period in all of the lakes except Hams, where samples were collected for only four months. However, growth was estimated for the entire year. In 1980 stomach samples were collected for five months whereas growth was measured for a nine-month period. It is possible but not probable that fish in one population did most of their feeding and growing when samples were not being collected, while fish in other lakes happened to feed and grow primarily during the months of sampling. Furthermore, samples were collected throughout the warmer seasons (May to October in 1979 and May to September in 1980) when feeding, growth and digestive rates should have been greater than during the colder seasons. Presumably much of the energy consumed during spring was expended for spawning. Thus, even if feeding patterns during the warmer months were very different from those during the remainder of the year it seems that the period most significant, in terms of feeding and growth, was studied. Another possibility is different caloric contents of various forage organisms. However, there was no indication that fast growing fish consistently ate items with different per unit volume caloric content than those eaten by slow growing fish.

The assumption that average volume of stomach contents is a relative measure of energy intake could not be substantiated. However, a variety of evidence tends to support this assumption and no evidence was found that discredited it.

The assumption that digestive efficiency was similar for all the crappie populations is also difficult to evaluate. Presumably digestive efficiency is dependent on the type of organisms being digested, but we have no specific information on the digestibility of the various taxa. However, based on current knowledge this assumption also seems reasonable. If both assumptions are valid then differences in total metabolism of fish from the different lakes may be responsible for the results obtained.

Total metabolism as discussed by Paloheimo and Dickie (1965; 1966a, 1966b) includes energy used for maintenance and activity. Since this energy is affected by many factors, the assumption that total metabolism was similar for fish from all populations may not be true. Ration size and temperature are two of the factors that affect total metabolism of fish. As temperature increases total metabolism increases and, given a constant energy supply, less energy is available for growth (Paloheimo and Dickie 1966b). However, as discussed previously, the effect of a temperature difference on total metabolism was countered by differences in digestion rates and the methods of measurements of food consumption. Although the net effect is unknown, the data for 1980 indicate that differences in temperature did not effect growth.

Total metabolism is also affected by ration size. As the ration size of fish increases the proportion of the ration used for total metabolism increases, and the proportion available for growth decreases. As the proportion available for growth decreases, however, the absolute amount available for growth increases (Paloheimo and Dickie 1965). The result of this interaction is that a given change in the ration size is associated with a proportionally smaller change in growth, or a given change in growth should be associated with a proportionally greater change in ration size. Therefore, in this study where growth rates were statistically different, a clear difference in ration size would be expected to have been present.

Physiological factors, including salinity and concentration of metabolic wastes, and behavioral activity also affect total metabolism. For example, high salinity or concentrations of metabolic wastes increase the metabolic costs required to maintain osmotic balance in fish (Paloheimo and Dickie 1966b). Laboratory studies have shown that for certain species, a fish held as an individual has a higher metabolic rate than those allowed to school (Schuett 1933; Delco and Beyers 1963). Even the formation of hierarchies within groups of fish affect growth efficiency (Paloheimo and Dickie 1966b). Given these observations it seems reasonable to hypothesize that the ability to form and maintain schools, cover, predation, or feeding behavior might effect total metabolism as indicated. Type of forage, cover, forage abundance, variance in food distribution (Ivlev 1961), chasing or stalking of prey, and a wide variety of other factors can all influence feeding behavior and total metabolism of fish.

Abundance of forage in the environment seemed unrelated to importance in the diet of crappies. However, it is possible that changes in abundance of forage fish may have had a greater influence on the food habits of crappies than changes in abundance of benthic invertebrates and zooplankton. In addition, the estimates of benthic invertebrates and zooplankton abundance were probably not strictly comparable between lakes, and may not have been entirely comparable for different years within a given lake because of yearly differences in macrophyte growths.

Based on this evaluation it is my conclusion that the quantity and types of forage consumed were not related to the growth rates of fish in the four lakes studied. Further, I conclude that physiological and/or behavioral factors affected the metabolism and, therefore, the efficiency with which food was utilized. These conclusions appear to be consistent with the results of other studies on the relationship between diet and growth of crappies (Crawley 1954; Burris 1956; Seaburg and Moyle 1964). Crawley found that the quantity of food consumed was unrelated to growth and concluded that differences in the nutrient content of the items consumed were responsible for the differences in growth. In contrast, Burris found that some fast growing fish contained more food than slow growing fish; although the opposite was true for the size groups of crappies he concluded were "most severely stunted." Seaburg and Moyle found that a population of young fast growing crappie contained more than twice as much food as a population of older, slower growing individuals. The instances where fast growing crappies contained more food than slow growing crappies, and where type of forage appears inconsistent could easily be attributed to chance. Given these data previous workers seem to have somewhat reluctantly concluded that the types of forage determined growth rate. The contrasting conclusions of Crawley (1954) and Burris (1956) and the lack of a consistent pattern in the present study, taken together, however, suggest that the types of forage consumed is not closely related to growth.

It is obvious that my conclusions are in sharp contrast to the accepted interpretation of the reasons for crappie stunting given by other fishery biologists. However, this study together with those of other authors seem to unescapably lead me to the conclusion drawn. The quantities of forage consumed appeared to be unrelated to growth, indicating that differences in the amount of energy consumed did not determine growth rates. If energy consumption was similar, and growth differed, then it follows that the manor in which injested energy was utilized differed. Physiological factors and behavior affect metabolism and, therefore, may be responsible for the differences in growth.

CHAPTER V

SUMMARY AND CONCLUSIONS

Growth rates apparently were not determined by the quantity or types of forage present or consumed. However, seasonal and daily variations in feeding patterns could have biased the results, although other studies suggested that possibility was unlikely. Evaluation of the types of forage consumed did not indicate that differences in caloric content per unit volume of food were related to differences in growth. However, this aspect may warrant further investigation. Temperatures did not appear to differ enough to be responsible for a difference in digestive rates or total metabolism. It also appears unlikely that digestive efficiency would have been significantly different between populations. We suggest that physiological factors, such as high salinities or concentrations of metabolic wastes, or differences in feeding and schooling behavior could have resulted in differences in the total metabolism of individuals in the four populations.

Based on the findings of this study future studies should concentrate on validation of the assumptions involved in this and similar studies, and physiological and behavioral differences between populations. Since many studies indicate that growth is density dependent, monitoring of physiological and behavioral aspects potentially related to growth while altering densities might be a feasible approach.

Factors affecting mortality of crappies should also be investigated, since many crappie populations contain both slow growing individuals and a large proportion of fish that are age III and younger. Black crappies in Comanche Lake (which was unfished) grew at moderate rates, yet a very large proportion (83%) of these individuals were of a harvestable size (Appendix A). The same appears to be true in nearby Grama Lake, which is also unfished (unpublished data). Fishing mortality and predator-prey interactions of largemouth bass and crappie, as described by the theory of proportional stock density (Anderson 1976), may be important.

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APPENDIXES

APPENDIX A

NUMBER (FREQUENCY) OF BLACK AND WHITE CRAPPIE OF VARIOUS LENGTHS AND AGES IN FOUR LAKES, 1979-80

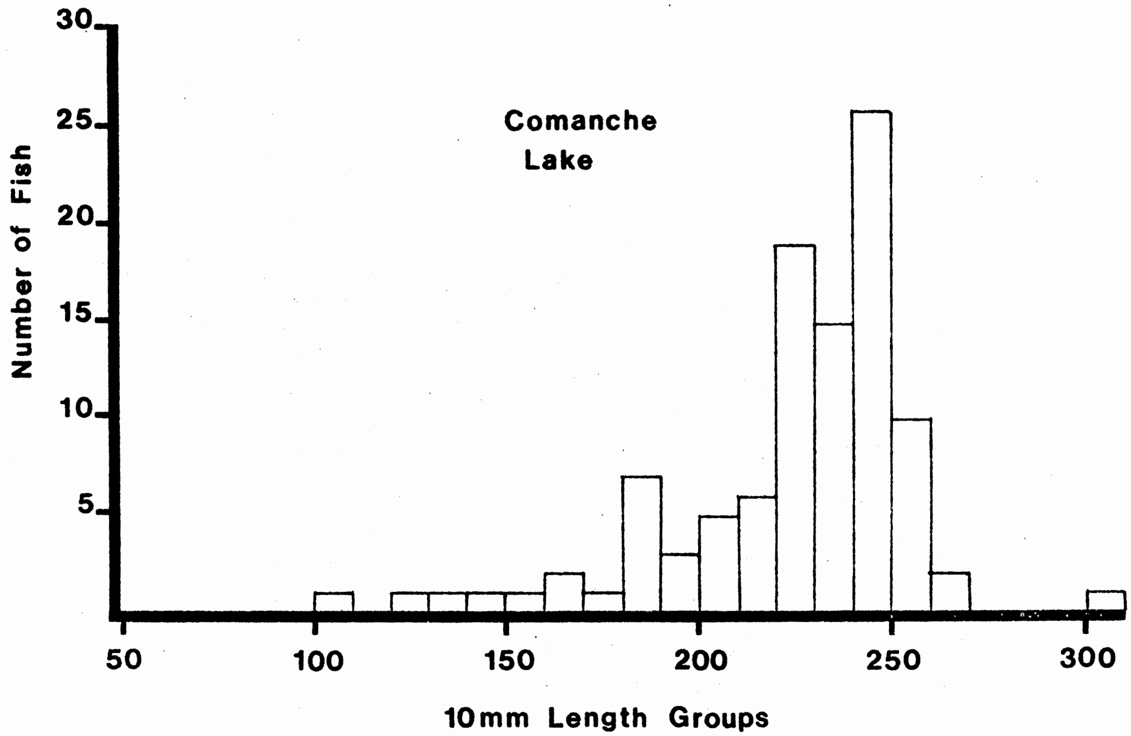
Some observations can be made from length and age frequencies; however, additional information would be required before any final conclusions can be made. The graphs indicates that angler harvest and proportional stock density (Anderson 1976) could be more important than growth rates in determining the proportion of crappie of harvestable size in a population.

Fishing pressure varied greatly between the lakes. No fishing has been allowed in Comanche Lake; a very limited number of people have access to Hams Lake for fishing; and fishing pressure was relatively heavy on lakes George and Logan. Fishing from the bank was the primary method used on lakes George and Logan. Because Lake George was much larger and had dense beds of macrophytes along the shoreline for much of the year, harvest undoubtedly had much less impact on the fish populations in that lake than in Logan Lake.

The proportion of harvestable size crappie was inversely correlated with fishing pressure. The majority of black crappie in Comanche Lake (where no fishing has been allowed) were 200 mm or longer (Figures 5 and 6). Hams Lake, with limited fisherman access, had moderate numbers of black crappie over 200 mm; however, crappie in Lake George were slightly larger, on the average, than white crappie in Logan Lake (Figures 7 and 8).

Growth rates did not appear to be correlated with the proportion of crappie of harvestable size. Overall growth in Lake George was similar to growth in Comanche Lake and better than growth in Hams Lake, yet relatively few crappie of harvestable size were present in Lake George. In lakes George and Logan size distributions of white crappie were similar, although growth rates were different. Crappie

Figure 5. Length frequencies for black crappies from Comanche and Hams lakes, 1979.


Comanche
Lake
Number of Fish
30
25
20
15
10
5
50
100
150
200
250
300
10mm Length Groups

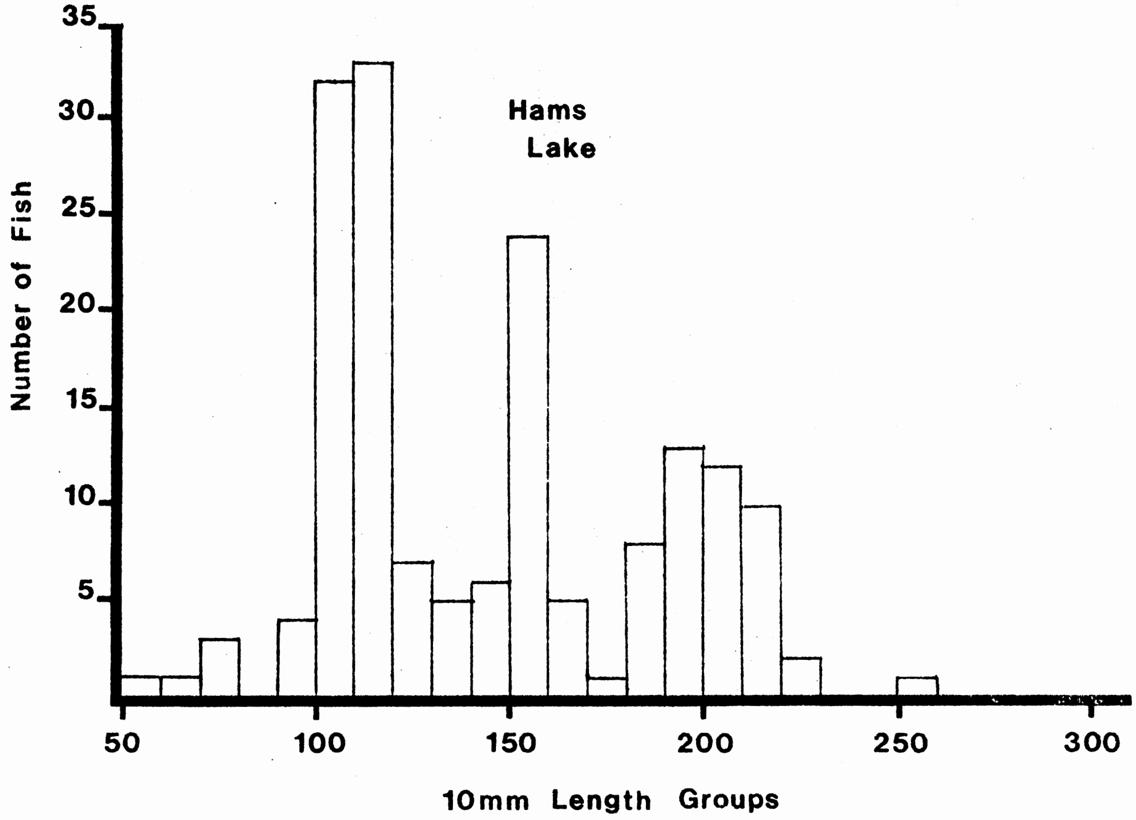
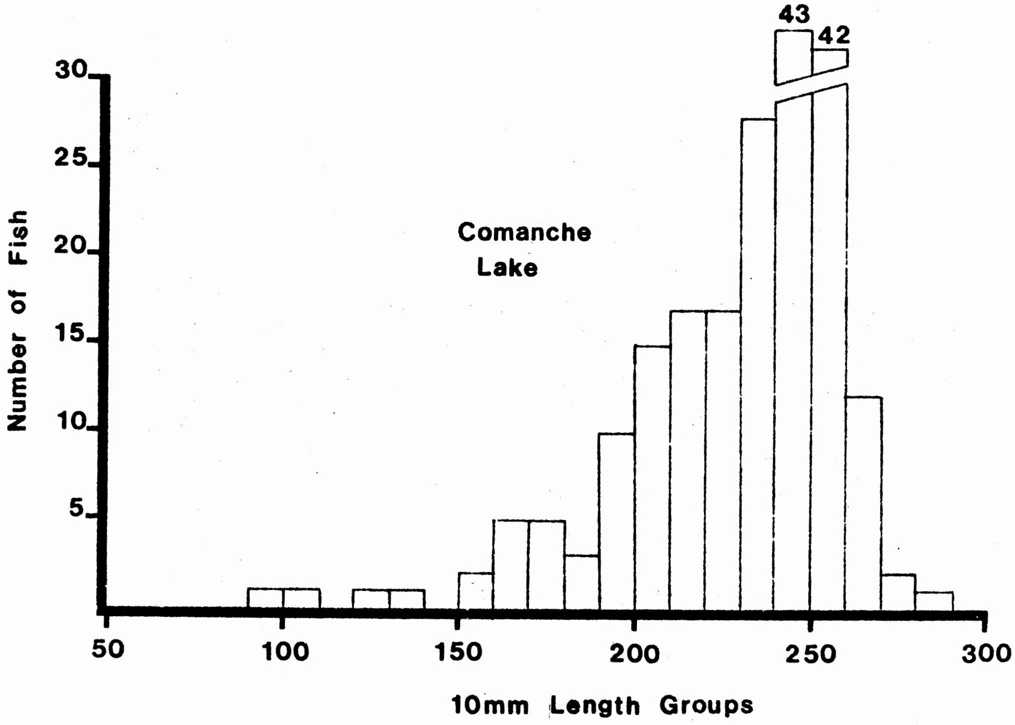

Hams
Lake
Number of Fish
35
30
25
20
15
10
5
50
100
150
200
250
300
10mm Length Groups

Figure 6. Length frequencies for black crappies from Comanche and Hams lakes, 1980.


43
42
30
25
20
15
10
5
Number of Fish
Comanche
Lake
50
100
150
200
250
300
10mm Length Groups

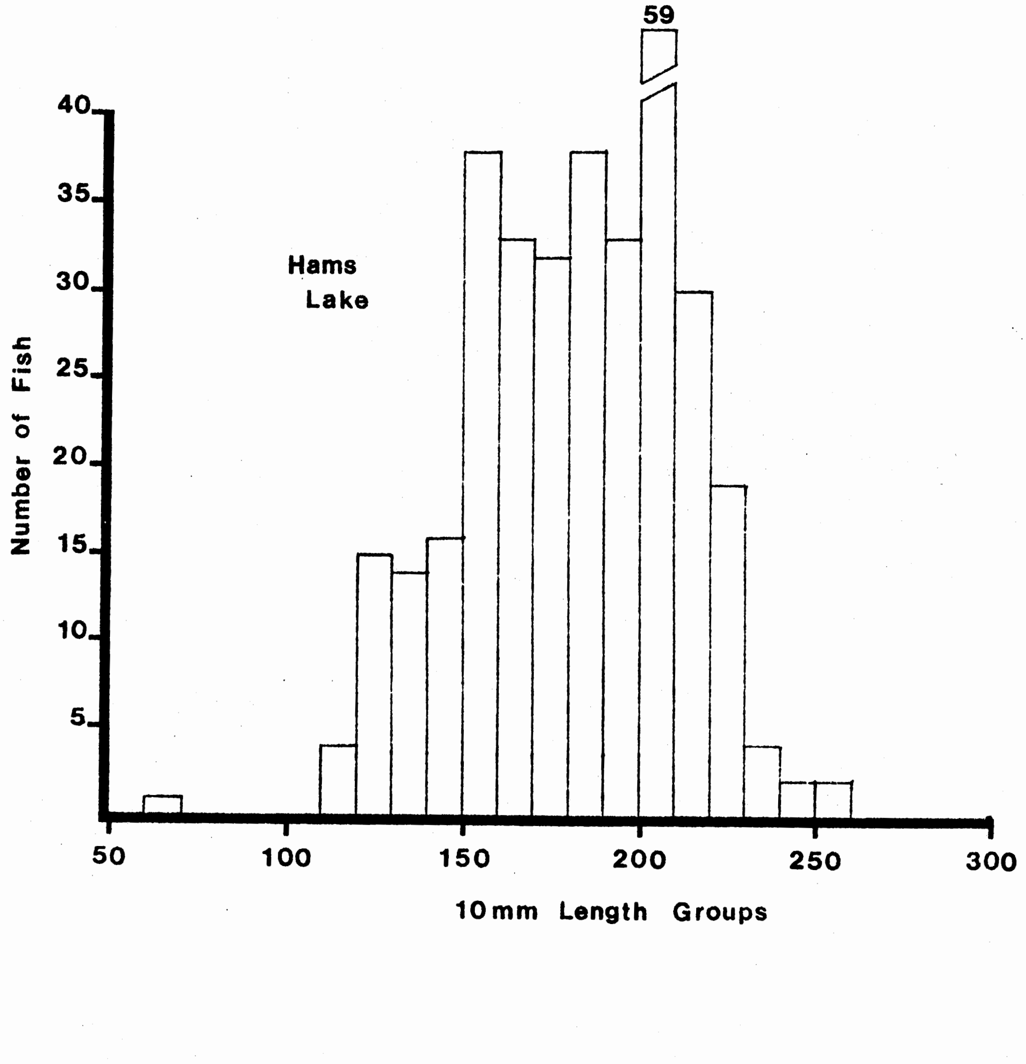
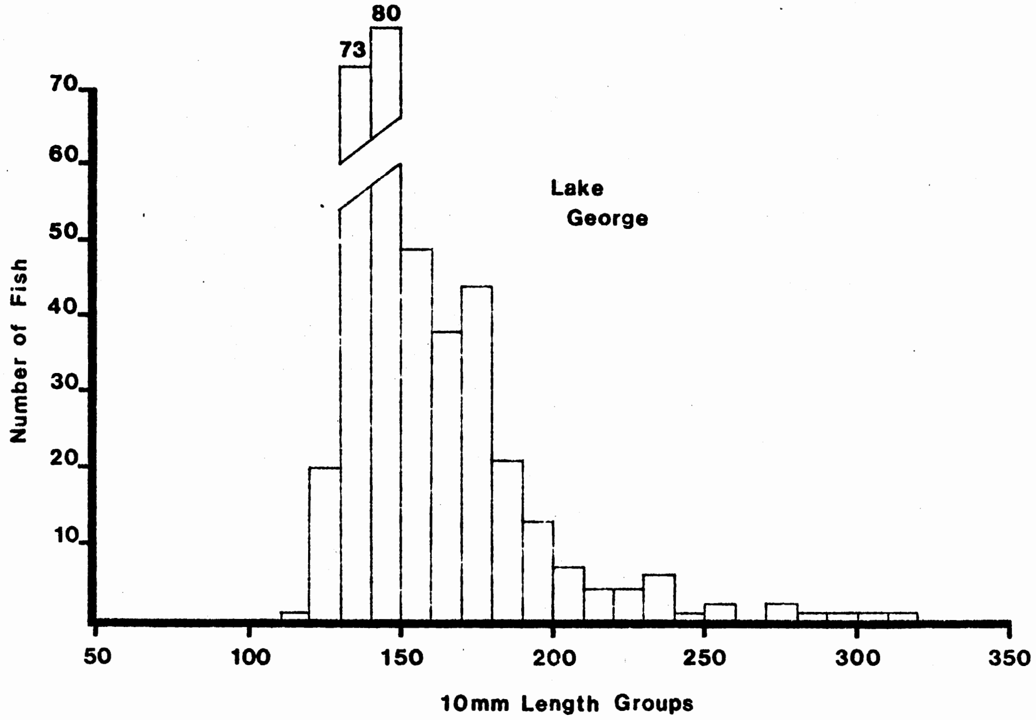

59
40
35
30
25
20
15
10
5
Number of Fish
Hams
Lake
50
100
150
200
250
300
10mm Length Groups

Figure 7. Length frequencies for white crappie from lakes George and Logan, 1979.


80
73
70
60
50
40
30
20
10
Number of Fish
Lake George
50
100
150
200
250
300
350
10mm Length Groups

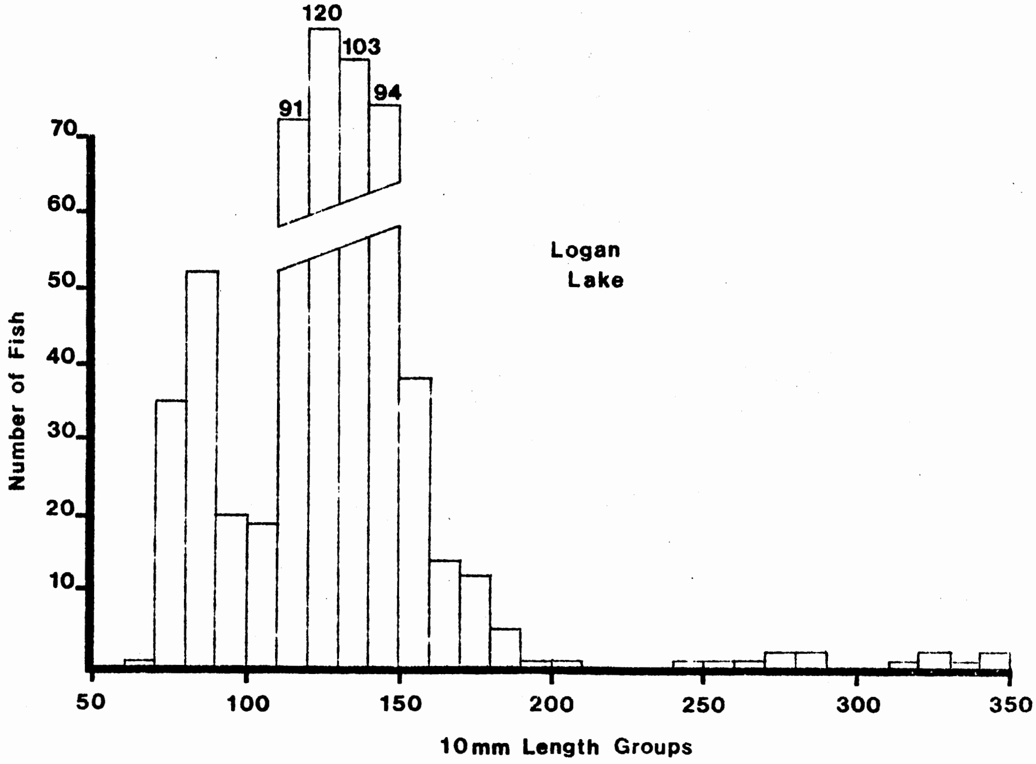
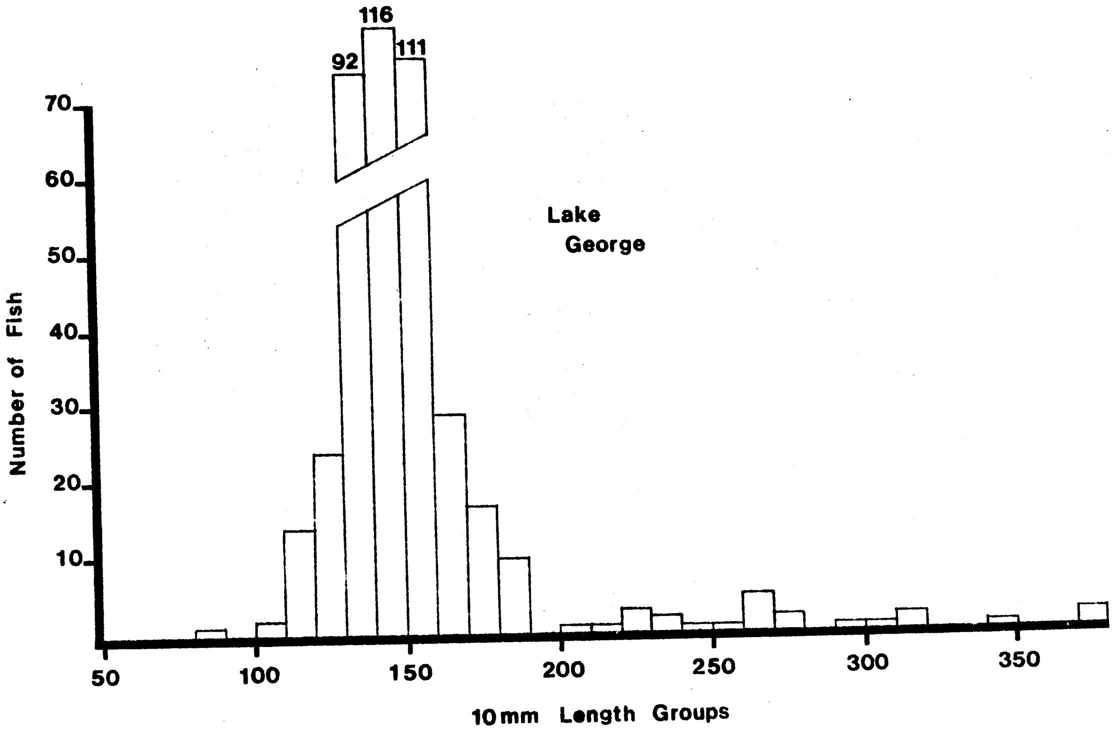
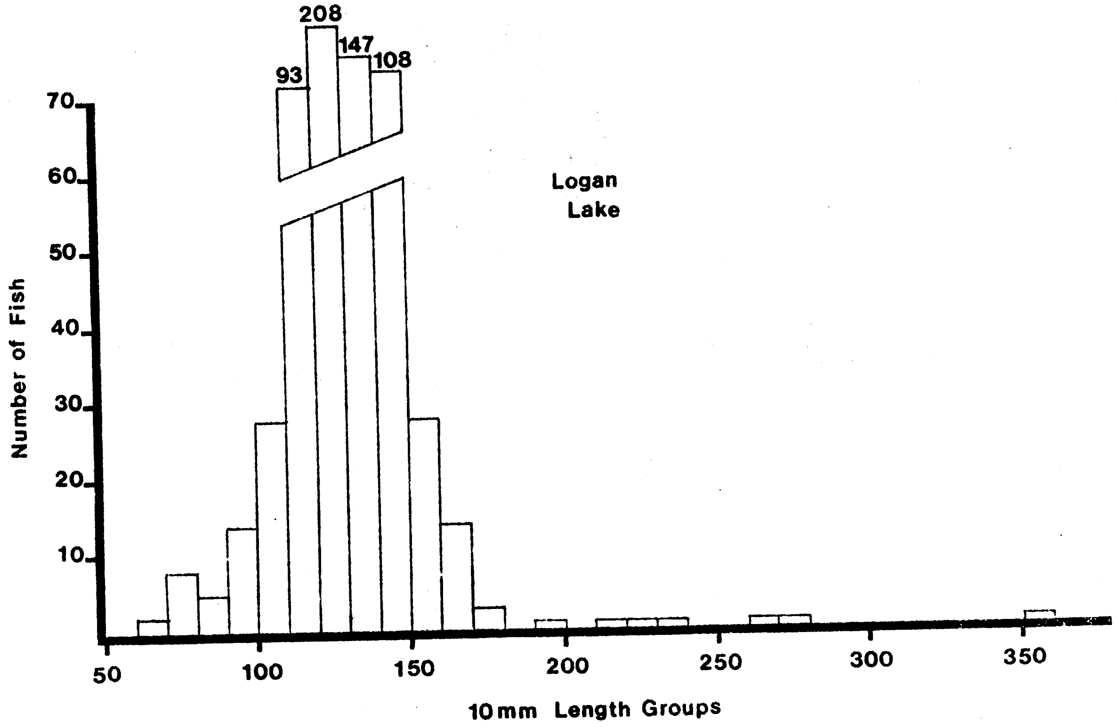

120
103
91
94
70
60
50
40
30
20
10
Number of Fish
Logan Lake
50
100
150
200
250
300
350
10mm Length Groups

Figure 8. Length frequencies for white crappie from lakes George and Logan, 1980.


116
92
111
70
60
50
40
30
20
10
Number of Fish
Lake George
50
100
150
200
250
300
350
10mm Length Groups

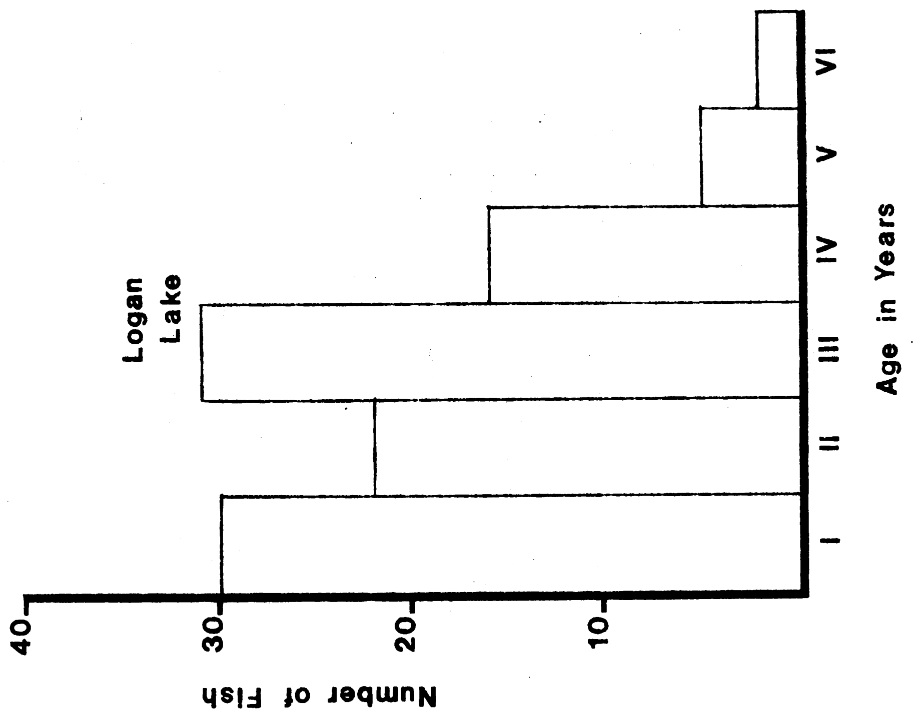

208
147
93
108
70
60
50
40
30
20
10
Number of Fish
Logan Lake
50
100
150
200
250
300
350
10mm Length Groups

from Hams and Logan lakes grew at similar rates and their size distributions were very different.

The absence of a relation between growth rates and size distributions in 1979 changed relatively little in 1980. Thus, the age distribution seem to be basically stable (Figures 9, 10, 11, and 12). The same age groups of crappie remained dominant instead of particular year classes.

The negative correlation between fishing pressure and proportion of large fish does not mean that angling was directly responsible for the lack of large crappie. Since interviews with fishermen indicated they had little interest in, and caught few crappie in the lakes, harvest of crappie did not appear to be great enough to be solely responsible for the observed differences in size distributions. Since most anglers fished for largemouth bass, predator-prey interactions between bass and crappie were probably the link between fishing pressure and size distribution of crappie. Unfortunately, we did not catch enough largemouth bass to determine their abundance and relative size in the four lakes.

Figure 9. Age frequencies for white crappie from lakes George and Logan, 1979.


Logan Lake
Number of Fish
40
30
20
10
I
II
III
IV
V
VI
Age in Years

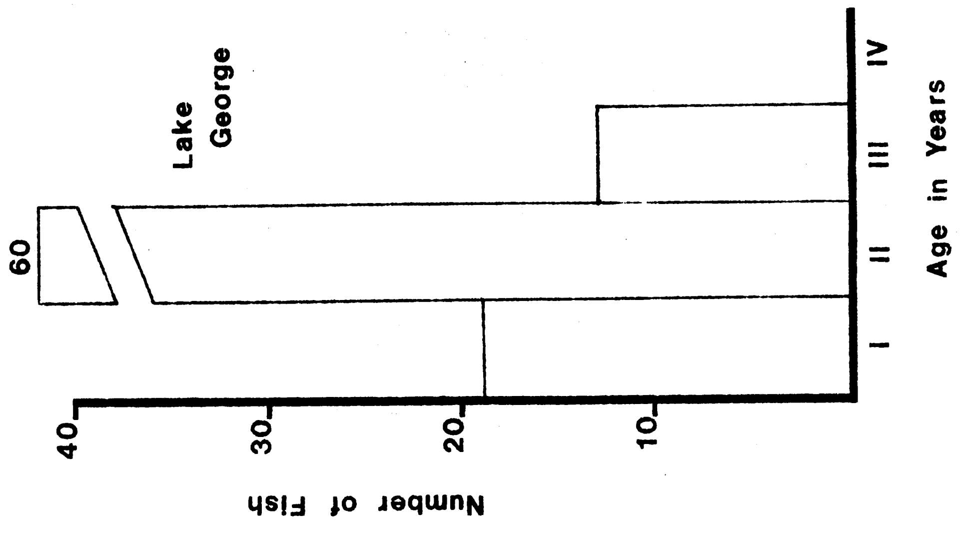
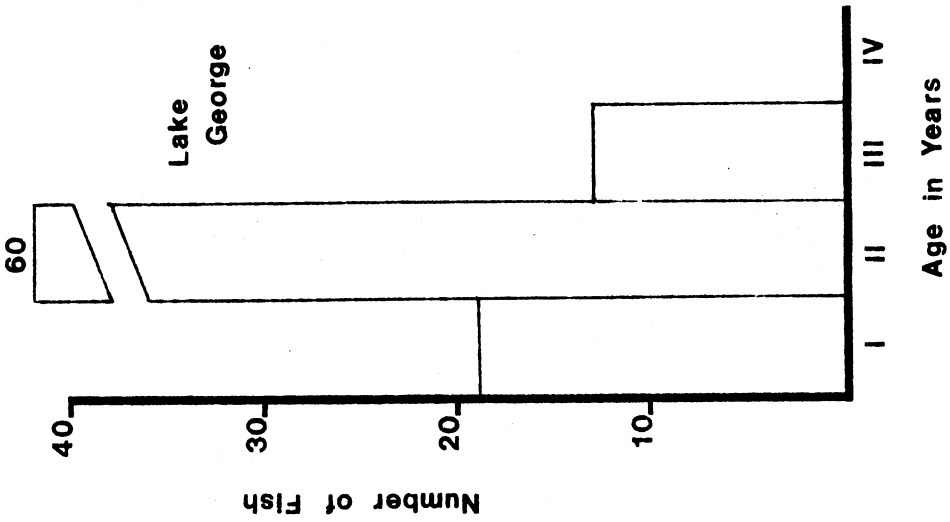

60
Lake George
Number of Fish
40
30
20
10
I
II
III
IV
Age in Years

Figure 10. Age frequencies for white crappie from lakes George and Logan, 1980.


Number of Fish
40
30
20
10
60
Lake George
I
II
III
IV
Age in Years

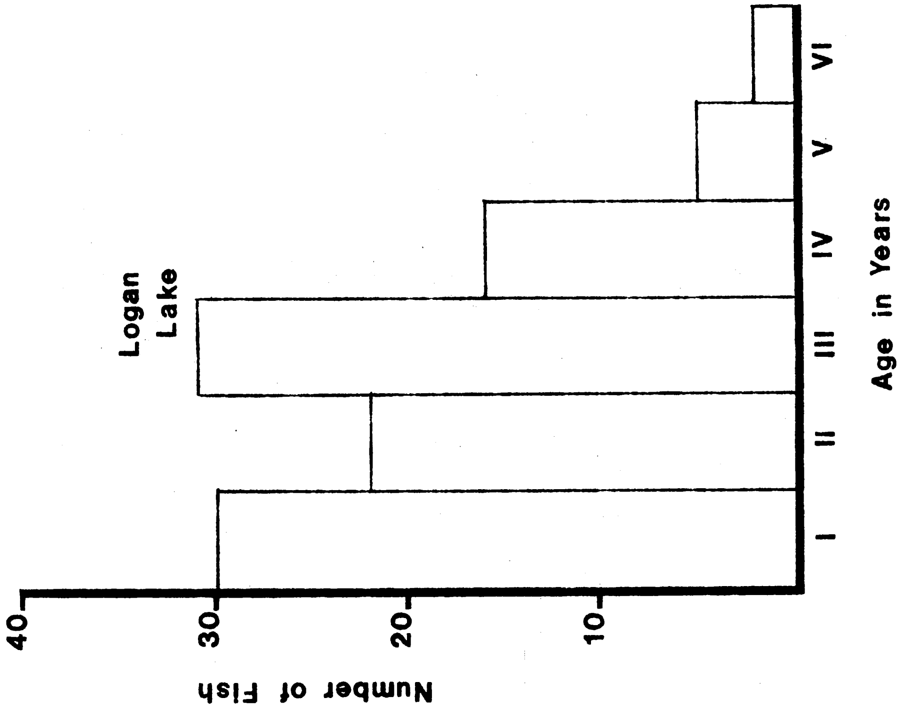
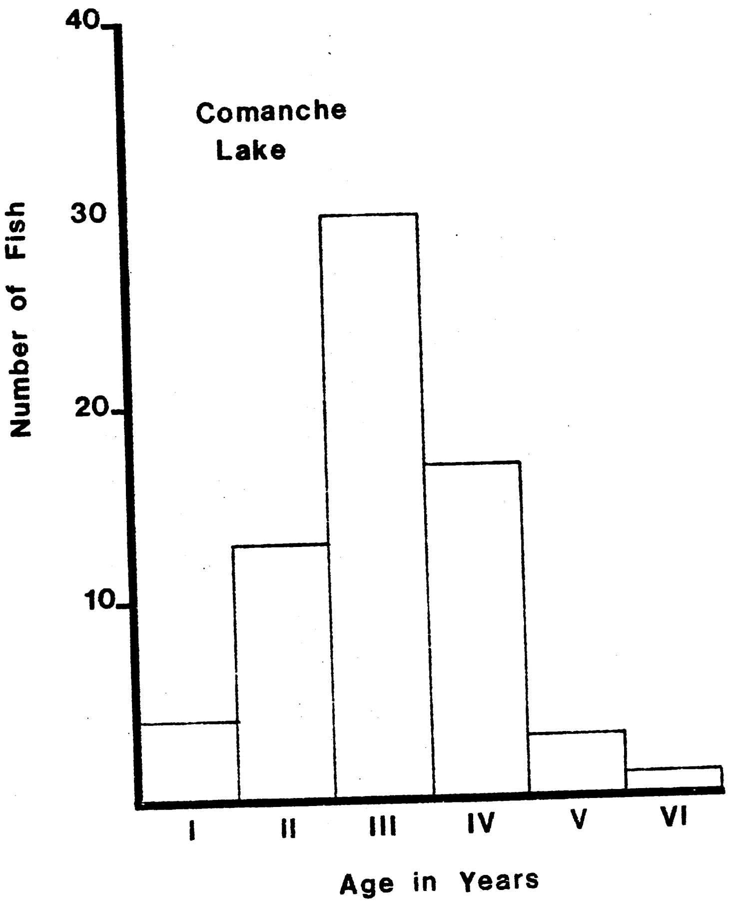

Number of Fish
40
30
20
10
Logan Lake
I
II
III
IV
V
VI
Age in Years

Figure 11. Age frequencies for black crappie from Comanche and Hams lakes, 1979.


Comanche
Lake
Number of Fish
40
30
20
10
I
II
III
IV
V
VI
Age in Years

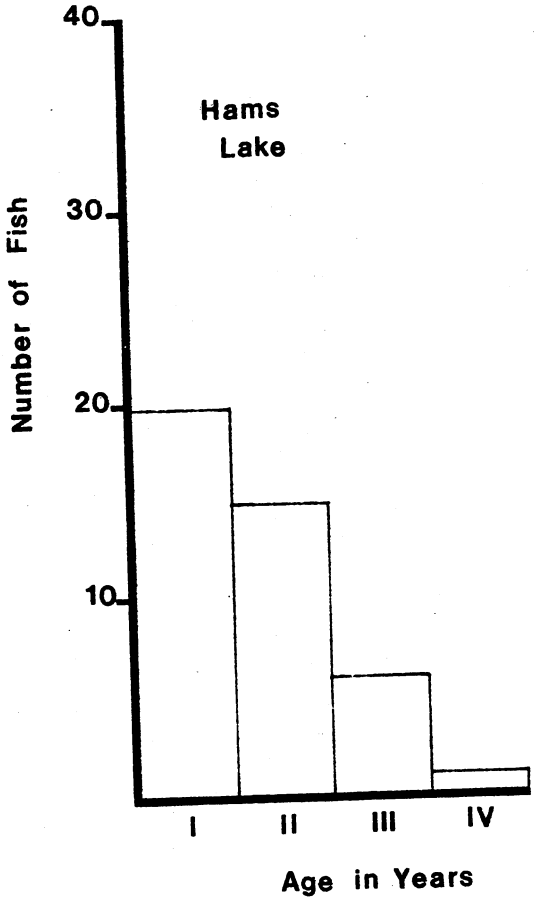
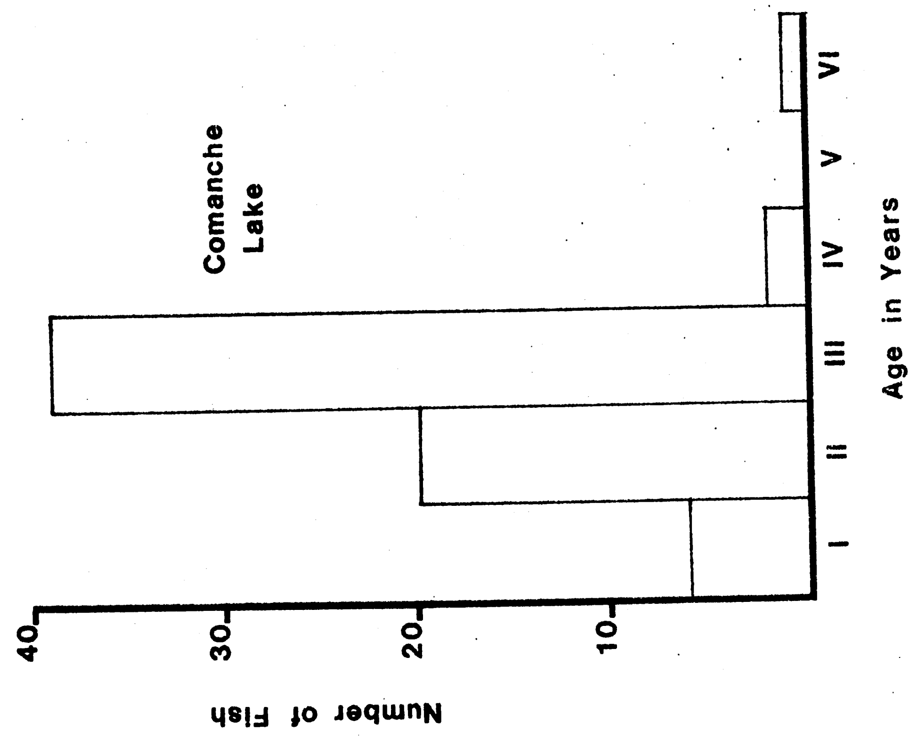
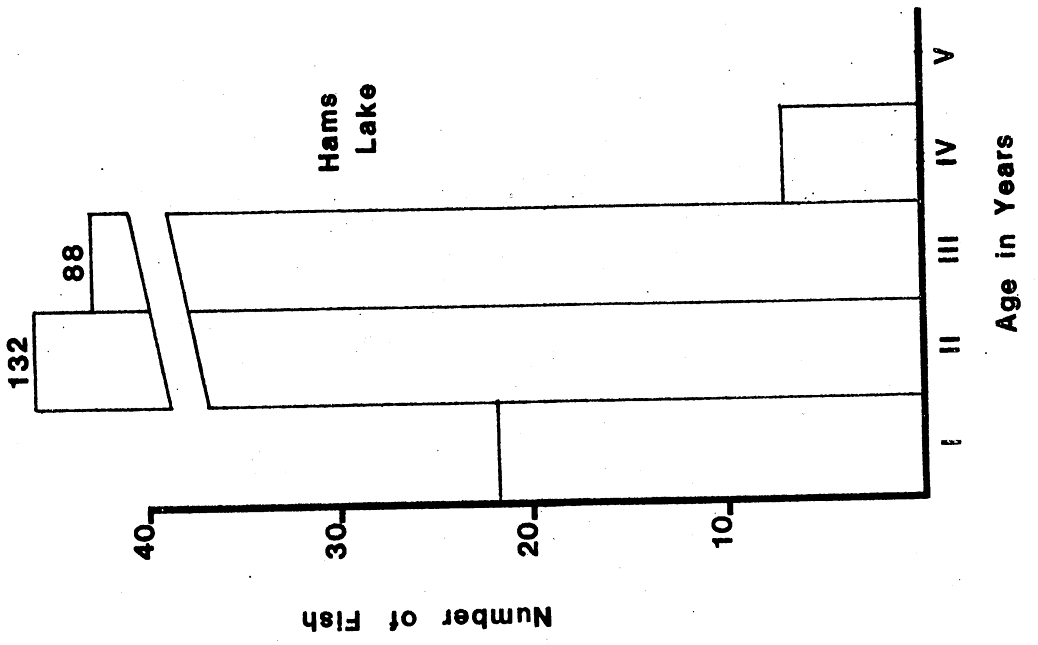

Hams
Lake
Number of Fish
40
30
20
10
I
II
III
IV
Age in Years

Figure 12. Age frequencies for black crappie from Comanche and Hams lakes, 1980.


Comanche Lake
Number of Fish
40
30
20
10
I
II
III
IV
V
VI
Age in Years


Hams Lake
Number of Fish
40
30
20
10
132
88
I
II
III
IV
V
Age in Years

APPENDIX B

NUMBERS AND MEAN COEFFICIENTS OF CONDITION (K) OF WHITE AND BLACK CRAPPIES OF VARIOUS LENGTHS, DURING 1979 AND 1980

Table 12. Numbers and mean coefficients of condition ($\bar{K}$) of white crappie of various lengths from lakes George and Logan, April to August 1979.

	Lake George		Lake Logan	
Length (mm)	Number	K	Number	K
81 - 100	-	-	21	0.940
101 - 120	-	-	29	1.029
121 - 140	34	1.035	52	0.965
141 - 160	49	0.998	22	0.860
161 - 180	28	0.937	9	1.016
181 - 200	12	0.989	2	0.987
201 - 220	7	1.021	2	1.045
221 - 240	7	1.113	-	-
241 - 260	2	1.096	2	1.378
261 - 280	-	-	4	1.229
281 - 300	-	-	1	1.528
301 - 320	2	1.325	-	-
321 - 340	-	-	1	1.311
341 - 360	-	-	1	1.363

Table 13. Numbers and mean coefficients of condition (K) for black crappie of various lengths from lakes Comanche (March to June) and Hams (July), 1979.

	Hams Lake		Comanche Lake	
Length (mm)	Number	K	Number	K
81 - 100	6	1.215	-	-
101 - 120	49	1.097	1	1.224
121 - 140	7	1.131	-	-
141 - 160	17	1.137	1	1.145
161 - 180	2	1.368	2	1.362
181 - 200	6	1.236	4	1.364
201 - 220	12	1.100	1	1.456
221 - 240	4	1.157	9	1.312
241 - 260	1	1.168	3	1.001

Table 14. Numbers and mean coefficients of condition (K) for white crappie of various lengths from Comanche and Hams lakes, 1980.

	Comanche Lake		Hams Lake	
Length (mm)	Number	K	Number	K
81 - 100	1	1.13	-	-
101 - 120	1	1.28	5	1.09
121 - 140	2	1.23	27	1.15
141 - 160	2	1.30	62	1.23
161 - 180	11	1.20	69	1.25
181 - 200	13	1.22	66	1.28
201 - 220	30	1.22	81	1.25
221 - 240	49	1.22	19	1.22
241 - 260	86	1.10	3	1.41
261 - 280	15	1.02	-	-
281 - 300	1	0.77	-	-

Table 15. Numbers and mean coefficients of condition (K) for white crappie of various lengths from lakes George and Logan, 1980.

Length (mm)	Lake George		Lake Logan	
	Number	K	Number	K
61 - 80	-	-	8	0.73
81 - 100	1	1.01	17	1.01
101 - 120	15	0.98	105	0.98
121 - 140	131	1.03	224	0.96
141 - 160	220	0.99	81	0.91
161 - 180	49	0.96	8	0.93
181 - 200	4	1.06	2	0.98
201 - 220	3	1.14	1	1.30
221 - 240	5	0.97	1	0.98
241 - 260	1	1.21	-	-
261 - 280	5	1.09	1	1.35
281 - 300	1	0.91	1	1.51
301 - 320	2	1.22	-	-
321 - 340	-	-	-	-
341 - 360	1	1.19	2	1.42
361 - 380	1	1.12	-	-

APPENDIX C

STOMACH CONTENTS OF BLACK AND WHITE CRAPPIE IN VARIOUS SIZE CLASSES, 1979 AND 1980

Table 16. Stomach contents of white crappie in various size classes from lakes George and Logan, 1979.

		Measurement and lake			
		Percent occurrence		Percent of total volume	
Size class (mm)	Food item	George	Logan	George	Logan
0-99	Diptera larvae				
	Chironomidae	-	50.0	-	7.7
	Chaoboridae	-	7.1	-	0.3
	Ceratopogomidae	-	7.1	-	0.3
	Diptera pupae	-	14.3	-	1.2
	Coleopteoa larvae	-	7.1	-	<0.1
	Amphipoda	-	7.1	-	0.2
	Cladocera	-	64.3	-	73.7
	Copepoda	-	57.1	-	13.9
	Ostracoda	-	64.3	-	2.7
100-149	Fish	13.3	2.9	5.4	<0.1
	Fish eggs	2.7	0.0	<0.1	0.0
	Diptera larvae				
	Chironomidae	36.0	41.4	9.6	21.8
	Chaoboridae	40.0	34.3	51.9	12.3
	Ceratopogonidae	10.7	1.4	2.1	<0.1
	Diptera Pupae	30.7	20.0	4.4	2.2
	Ephemeroptera nymphs				
	Hexagenia	0.0	2.9	0.0	1.3
	Caenidae	8.0	1.4	1.3	0.1
	Odonata nymphs				
	Dragonfly	1.4	0.0	1.3	0.0
	Damselfly	0.0	5.3	0.0	1.3
	Hemiptera	0.0	1.4	0.0	<0.1
	Trichoptera larvae	0.0	2.9	0.0	<0.1
	Insect parts	20.0	10.1	2.4	1.9
	Amphipoda	0.0	2.9	0.0	<0.1
	Cladocera	33.3	50.0	13.5	39.5
	Copepoda	68.0	74.3	3.3	19.5
	Ostracoda	64.0	15.7	1.6	<0.1
	Unidentified remains	12.0	2.0	3.2	<0.1

Table 16. Continued.

Size class (mm)	Food item	Percent occurrence		Percent of total volume	
		George	Logan	George	Logan
150-	Fish	23.3	43.8	77.4	86.7
	Diptera larvae				
	Chironomidae	44.6	31.3	2.6	4.9
	Chaoboridae	26.8	18.8	3.7	0.3
	Ceratopogonidae	23.2	0.0	0.4	0.0
	Diptera pupae	37.5	18.8	2.3	<0.1
	Ephemeroptera nymph				
	Hexagenia	3.6	18.8	0.7	1.9
	Caenidae	14.3	0.0	0.4	0.0
	Odonata nymphs				
	Dragonfly	1.8	12.5	0.4	4.1
	Damselfly	14.3	0.0	1.8	0.0
	Hemiptera				
	Coriidae	1.8	12.5	<0.1	<0.1
	Coleoptera adult	3.6	0.0	<0.1	0.0
	Insect parts	10.7	18.8	<0.1	<0.1
	Amphipoda	14.3	0.0	0.2	0.0
	Cladocera	33.9	18.8	9.6	1.4
	Copepoda	35.7	25.0	0.1	0.8
	Ostracoda	48.2	6.3	0.1	<0.1
	Unidentified remains	12.5	0.0	0.3	0.0

Table 17. Stomach contents of white crappie in various size classes from lakes George and Logan, 1980.

Size class (mm)	Food item	Measurement and lake			
		Percent occurrence		Percent of total volume	
		George	Logan	George	Logan
0-99	Diptera larvae				
	Chironomidae	100.0	0.0	89.5	0.0
	Chaoboridae	0.0	45.5	0.0	15.8
	Ephemeroptera nymphs				
	<u>Hexagenia</u>	0.0	9.1	0.0	76.5
	Coleoptera adult	0.0	9.1	0.0	<0.1
	Cladocera	0.0	45.5	0.0	6.9
	Copepoda	100.0	63.6	9.5	0.7
	Ostracoda	100.0	0.0	1.0	0.0
100-150	Fish	5.8	9.2	<0.1	73.6
	Diptera larvae				
	Chironomidae	20.9	18.5	9.5	4.3
	Chaoboridae	57.0	53.8	34.6	8.0
	Ceratopogonidae	7.0	6.2	0.2	1.1
	Diptera pupae	2.3	0.0	0.4	0.0
	Ephemeroptera nymph				
	<u>Hexagenia</u>	2.3	4.6	0.1	9.9
	Caenidae	2.3	0.0	0.1	0.0
	Odonata nymph				
	Dragonfly	5.8	1.5	32.3	1.8
	Damselfly	17.4	0.0	17.9	0.0
	Amphipoda	4.7	0.0	<0.1	0.0
	Cladocera	58.1	50.8	3.3	1.0
	Copepoda	67.4	41.5	1.4	0.3
	Ostracoda	44.8	4.6	0.1	<0.1
150-	Fish	26.9	35.3	79.2	83.2
	Diptera larvae				
	Chironomidae	34.6	17.6	1.9	0.3
	Chaoboridae	51.9	29.4	7.9	0.5
	Ceratopogonidae	11.5	17.6	0.1	<0.1
	Ephemeroptera nymphs				
	<u>Hexagenia</u>	0.0	5.9	0.0	1.3
	Odonata nymphs				
	Dragonfly	7.7	0.0	2.4	0.0
	Damselfly	21.2	0.0	5.3	0.0

Table 17. Continued.

Size class (mm)	Food item	Measurement and lake			
		Percent occurrence		Percent of total volume	
		George	Logan	George	Logan
150-	Coleoptera adult	1.9	0.0	<0.1	0.0
	Crayfish	0.0	5.9	0.0	13.1
	Cladocera	32.7	23.5	0.4	<0.1
	Copepoda	36.5	17.6	<0.1	<0.1
	Ostracoad	17.3	5.9	<0.1	<0.1
	Unidentified remains	80.8	64.7	2.8	1.6

Table 18. Stomach contents of black crappie in various size classes from Comanche and Hams lakes, 1979.

Size class (mm)	Food item	Percent occurrence		Percent of total volume	
		Comanche	Hams	Comanche	Hams
0-99	Fish	-	14.3	-	47.0
	Diptera larvae				
	Chironomidae	-	14.3	-	1.2
	Insect parts	-	28.6	-	<0.1
	Copepoda	-	85.7	-	51.9
100-149	Fish	66.7	0.0	49.1	0.0
	Diptera larvae				
	Chironomidae	33.3	21.1	0.8	4.9
	Chaoboridae	33.3	15.8	29.8	0.7
	Ceratopogonidae	0.0	10.5	0.0	0.4
	Diptera pupae	66.7	5.3	6.0	0.8
	Odonata nymphs				
	Damselfly	33.3	0.0	3.3	0.0
	Insect parts	0.0	21.1	0.0	<0.1
	Amphipoda	66.7	5.3	2.7	0.2
	Cladocera	0.0	15.8	0.0	0.7
	Copepoda	0.0	89.5	0.0	62.1
	Unidentified remains	33.3	15.8	8.2	30.3
150-	Fish	22.0	19.2	11.0	34.6
	Diptera larvae				
	Chironomidae	54.0	19.2	7.2	2.9
	Chaoboridae	28.0	15.4	18.1	1.0
	Ceratopogonidae	38.0	0.0	2.3	0.0
	Diptera pupae	44.0	14.4	15.0	3.7
	Ephemeroptera nymph				
	Hexagenia	0.0	15.4	0.0	13.9
	Caenidae	32.0	7.7	7.3	0.6
	Baetidae	0.0	3.8	0.0	2.8
	Odonata nymph				
	Dragonfly	0.0	15.4	0.0	10.4
	Damselfly	4.0	7.7	0.3	4.2
	Coleoptera larvae	-	3.8	-	<0.1
	Hemiptera corixidae	2.0	0.0	<0.1	0.0
	Insect parts	14.0	11.5	5.7	10.4
	Amphipoda	34.0	7.7	1.4	<0.1
	Cladocera	62.0	15.4	20.4	0.2
	Copepoda	44.0	15.4	1.4	4.6
	Ostracoda	4.0	0.0	<0.1	0.0
	Unidentified remains	16.0	30.8	10.0	10.4

Table 19. Stomach contents of black crappie in various size classes from Comanche and Hams lakes, 1980.

Size class (mm)	Food item	Measurement and lake			
		Percent occurrence		Percent of total volume	
		Comanche	Hams	Comanche	Hams
0-99	Diptera larvae				
	Chaoboridae	100.0	50.0	57.0	8.6
	Odonata nymph				
	Damselfly	50.0	0.0	16.5	0.0
	Cladocera	0.0	50.0	0.0	1.1
	Copepoda	100.0	100.0	26.4	90.1
	Ostracoda	0.0	50.0	0.0	0.2
100-149	Fish	100.0	11.5	87.2	8.4
	Diptera larvae				
	Chironomidae	100.0	11.5	2.4	0.9
	Chaoboridae	100.0	50.0	1.8	36.5
	Ceratopogonidae	0.0	15.4	0.0	1.2
	Ephemeroptera nymphs				
	Hexagenia	0.0	23.1	0.0	27.7
	Caenidae	0.0	3.8	0.0	0.3
	Odonata nymphs				
	Dragonfly	0.0	3.8	0.0	5.0
	Damselfly	100.0	3.8	5.8	2.5
	Amphipoda	100.0	11.5	1.9	0.7
	Cladocera	0.0	38.5	0.0	1.6
	Copepoda	100.0	34.6	0.9	2.6
	Ostracoda	0.0	3.8	0.0	<0.1
	Unidentified remains	100.0	23.1	<0.1	12.5

Table 19. Continued.

Size class (mm)	Food item	Measurement and lake			
		Percent occurrence		Percent of total volume	
		Comanche	Hams	Comanche	Hams
150-	Fish	8.3	28.0	8.9	76.1
	Diptera larvae				
	Chironomidae	52.8	25.8	14.7	0.4
	Chaoboridae	90.3	37.6	26.8	2.8
	Ceratopogonidae	55.6	6.5	1.9	0.1
	Diptera Pupae	13.9	2.2	1.8	<0.1
	Ephemeroptera nymphs				
	Hexagenia	0.0	29.0	0.0	5.3
	Caenidae	19.4	1.1	7.4	0.3
	Odonata nymphs				
	Dragonfly	15.3	4.3	13.7	1.0
	Damselfly	33.3	2.2	13.0	2.1
	Coleoptera larvae	2.8	1.1	<0.1	<0.1
	Amphipoda	54.2	16.1	2.2	0.1
	Cladocera	69.4	32.3	3.7	0.1
	Copepoda	51.4	28.0	0.2	0.3
	Ostracoda	2.8	4.3	<0.1	<0.1
	Unidentified remains	69.4	68.8	5.7	11.7

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VITA

William Francis Schoch

Candidate for the Degree of

Master of Science

Thesis: POSSIBLE CAUSES OF THE SMALL AVERAGE SIZE OF CRAPPIE IN SOME OKLAHOMA RESERVOIRS

Major Field: Zoology

Biographical:

Personal Data: Born on November 17, 1955, in Schenectady, New York, the son of Wilhelm and Frances Schoch.

Education: Graduated from Shenendehowa High School, Elnora, New York, June 1973; received the Bachelor of Science degree from Cornell University, Ithaca, New York, May 1977; completed requirements for the Master of Science degree in Zoology at Oklahoma State University, Stillwater, Oklahoma, December, 1981.

Professional Experience: Fishery Technician, June through August, 1975, and Limnology Technician, June through August, 1976, with the Cornell Biological Field Station, Bridgeport, New York; Fishery Technician with NALCO Environmental Sciences, Syracuse, New York, June 1977 through August 1978; Graduate Research Assistant with the Oklahoma Cooperative Fishery Research Unit, Oklahoma State University, Stillwater, Oklahoma, August 1978 through February 1981.

Professional Affiliations: American Fisheries Society.